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**THE LAW SCHOOL**  
Abrams Environmental  
Law Clinic

July 26, 2024

*Via E-Filing*

Ms. Lisa Felice  
Executive Secretary  
Michigan Public Service Commission  
7109 West Saginaw Highway  
Lansing, MI 48917

RE: MPSC Case No. U-21534

Dear Ms. Felice:

Please find enclosed the Accompanying Exhibits DAO-279 to DAO-291 (Part 4 of 4) for the Direct Testimony of Arjun Makhijani on Behalf of Soulardarity and We Want Green, Too, along with proof of service for electronic filing in the above-referenced matter. Please do not hesitate to contact me with any questions or comments.

Sincerely,

A handwritten signature in black ink, appearing to read "Mark N. Templeton".

Mark N. Templeton, *pro hac vice*  
6020 S. University Avenue  
Chicago, IL 60637  
Phone: (773) 702-9611  
Email: templeton@uchicago.edu

xc: Parties to Case No. U-21534



# Housing Characteristics and Energy Burden Analysis for Highland Park, Michigan

Patrick Gibbs  
National Renewable Energy Laboratory (NREL)  
March 2024  
DOE/GO-102024-6090

# Notice

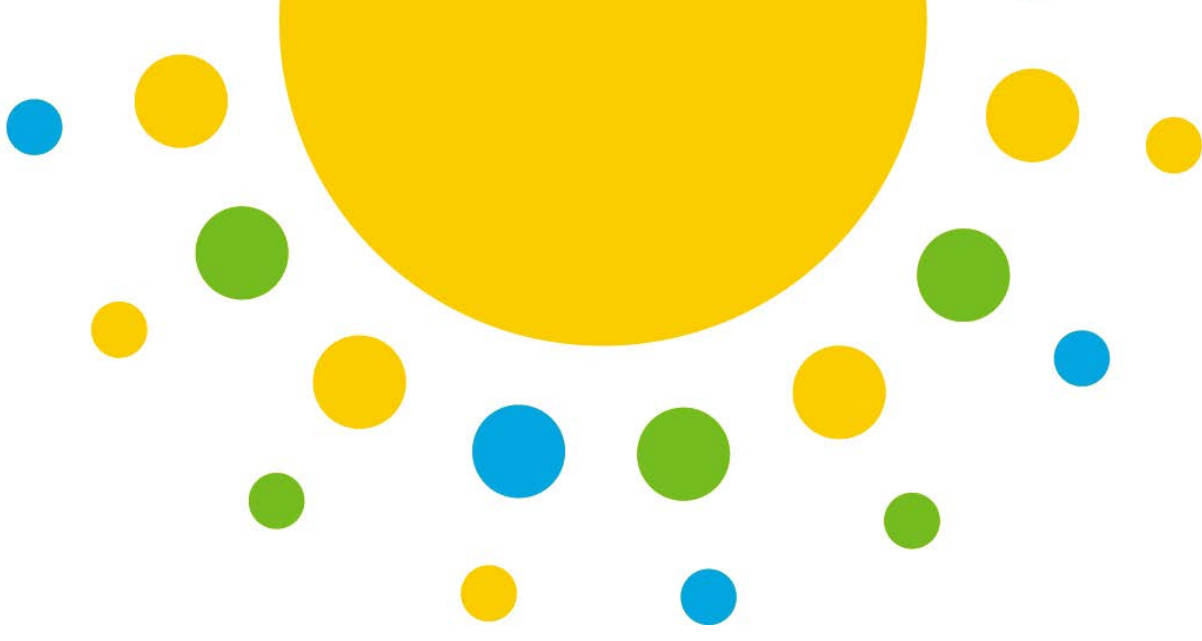
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# Communities LEAP (Local Energy Action Program)

## Scoping Context

Through the Communities LEAP Pilot, NREL engaged the Highland Park Stakeholder Coalition to scope four technical assistance work areas to address their energy needs and goals.

**This slide deck addresses the highlighted tasks under work area “C.”**

| A . City-Wide Solar Street Lighting and Policy Analysis                                                                                                                                                                                                                                                                                                | B. Grid Analysis                                                                                                                                                                                                                                                                                                                                                     | C. Community Choice: Home Energy Improvements                                                                                                                                                                         | D. Bonus Bucket: Transportation and Mobility with Michigan Clean Cities                                                                                                           |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"><li>Task 1: Solar street lighting financial model review.</li><li>Task 2: Due diligence references.</li><li>Task 3: Case studies for implementation.</li><li>Task 4: Master plan gap analysis.</li><li>Task 5: Zoning code and applications gap analysis.</li><li>Task 6: Review proposed solar ordinance.</li></ul> | <ul style="list-style-type: none"><li>Task 1: Determine existing load profile and feeder model (reference case).</li><li>Task 2: Grid analysis (limitations and capacity under three growth scenarios).</li><li>Task 3: Feasibility analysis of three actionable behind-the-meter projects (within the city’s authority under current grid configuration).</li></ul> | <ul style="list-style-type: none"><li>Task 1: Support a coalition-facilitated selection process.<ul style="list-style-type: none"><li>Task 2: Housing characteristics and energy burden analysis.</li></ul></li></ul> | <ul style="list-style-type: none"><li>Task 1: Coordinate with Michigan Clean Cities on feasibility study for perimeter loop micro-mobility utilizing electric shuttles.</li></ul> |



# Background

## Approaches to transition existing building stock to clean electricity include:

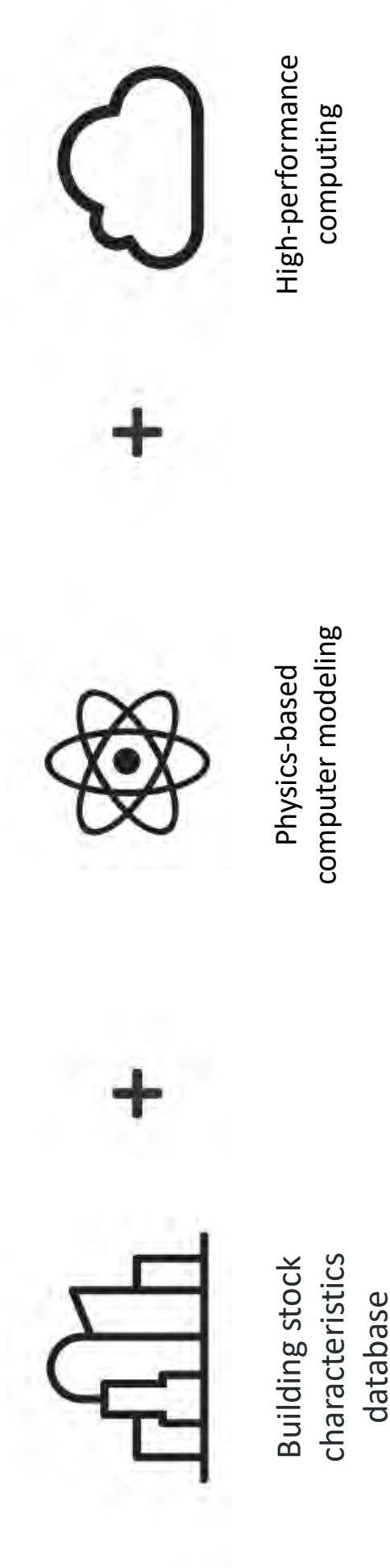
1. **Building electrification:** The adoption of technologies that use electricity in place of natural gas or other fossil fuels. Key examples include space heating and water heating technologies, appliances, and other equipment.
2. **Building envelope improvements:** Installing measures like insulation and air sealing that will reduce the energy needed for space heating and cooling.

**NREL researchers analyzed how building envelope and electrification upgrades to existing residential buildings in Highland Park, Michigan might impact the following areas:**

1. Energy consumption
2. Greenhouse gas (GHG) emissions
3. Energy burden
4. Utility bills.

# Data and Modeling Background

Analysis was built on energy consumption data modeled using the [ResStock™](#) tool.



NOTE: All figures in this presentation are from NREL's ResStock data unless otherwise noted.

ResStock version used: [September 2022](#), with the [2018 Actual Meteorological Year weather file](#).

# Assumptions and Limitations of Modeled Data

## Assumptions

- For emissions calculations, the grid prime energy mix is based on 2022 and will significantly change by 2035 based on the July 2023 settlement case.
- Utility bill data uses the current utility electricity and natural gas rates from DTE Energy.
- All upgrade costs are national averages. They do not reflect local market conditions such as labor rates and do not include rebates.
- Upgrade costs presented are the full costs of the upgrade and are not the incremental costs that might be seen if upgrading at time of replacement.
- Assumed performance of upgrade measures are summarized in Appendix 1; performance may vary substantially for upgrades to specific individual housing units and may change over time.
- Heat pumps are sized for cooling loads. This produces conservative estimates for heating dominant states.
- Households without existing cooling systems were assumed to use cooling after a heat pump upgrade, which adds a new service and improved thermal comfort, but can also substantially affect the cost-effectiveness of packages.

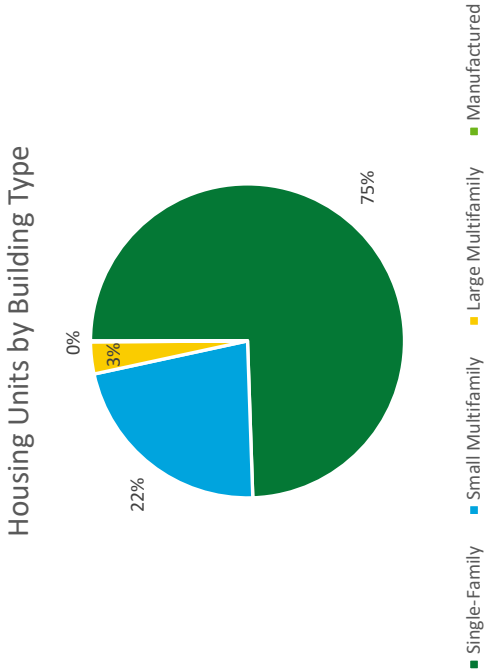
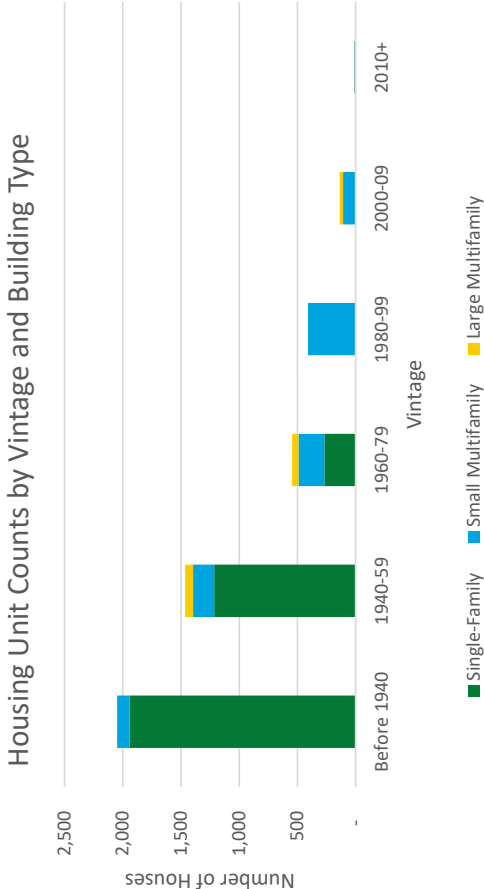
## Project Limitations

- The housing stock included in the analysis is based off modeled data and there are potential inaccuracies/uncertainties in the modeling (e.g., related in how the models represent the housing stock in Highland Park, Michigan).
- Analysis is based on modeled energy consumption patterns not actual/real-time utility data.
- Analysis does not include every possible building upgrade or combination of upgrades.

# Home Energy Improvements

## Building Stock

- There are an estimated 4,600 residential housing units in Highland Park, Michigan.
- 76% of Highland Park’s housing units were built before 1960. Older homes are predominantly single-family, while 74% of housing units built since 1960 have been multifamily housing.

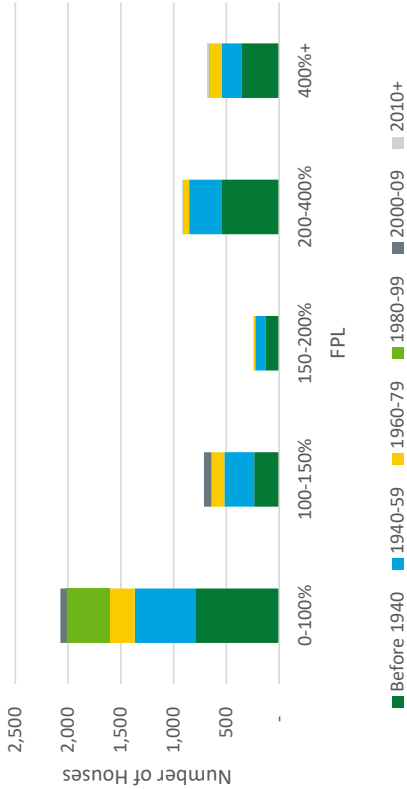


# Home Energy Improvements

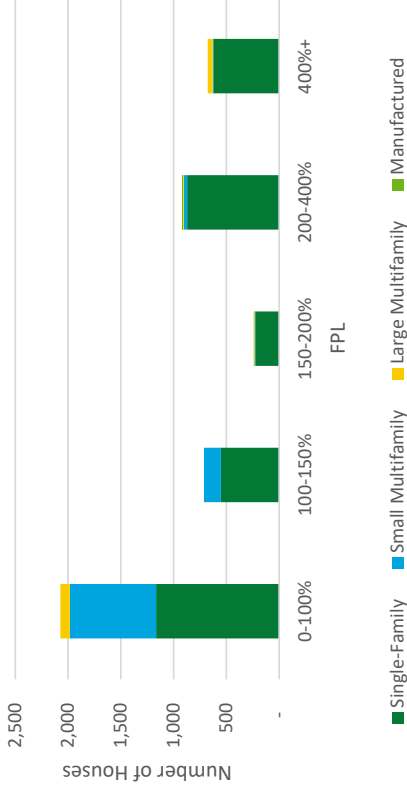
## Building Stock

- 65% of Highland Park residents make less than 200% of the Federal Poverty Level (FPL).
- Residents living below the 200% FPL and living in units built before 1960 make up 46% of all Highland Park residents.
- Residents living below the 200% FPL and living in single-family homes make up 42% of all residents. Of all residents living in multifamily housing, 92% make less than the 200% FPL.

Housing Counts by FPL and Vintage



Housing Counts by FPL and Building Type

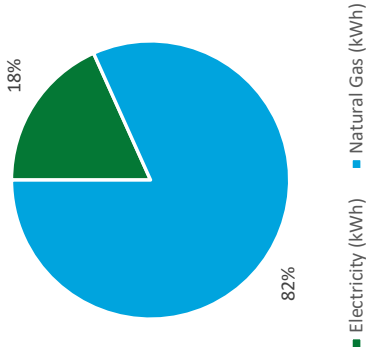


# Home Energy Improvements

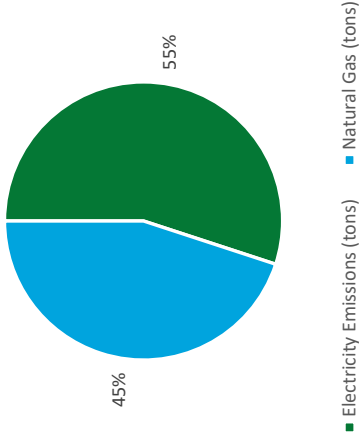
## Modeled Baseline Energy Consumption

- It is estimated that 82% of all housing site energy consumption in Highland Park is natural gas, while only 45% of energy emissions are due to natural gas.
- Electricity emissions (carbon dioxide equivalent) are weighted more heavily due to the relatively high percentage of coal in the DTE Energy fuel mix (55% coal).

Baseline Energy Consumption



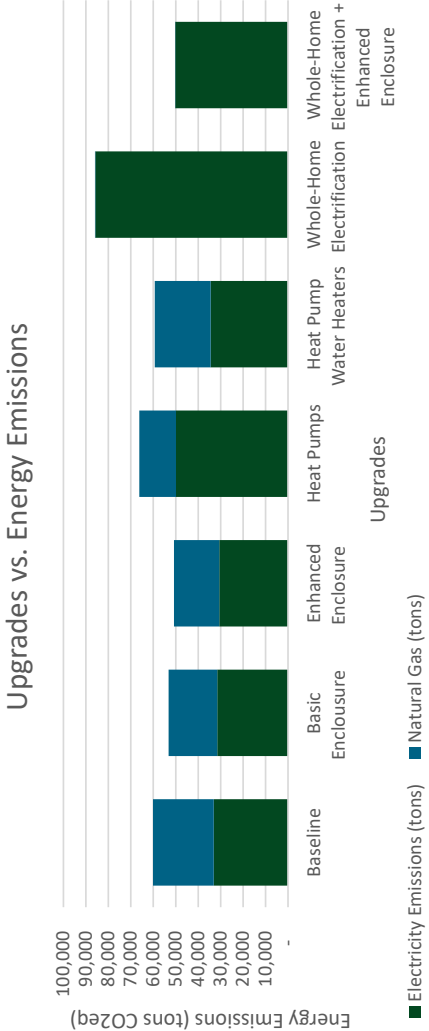
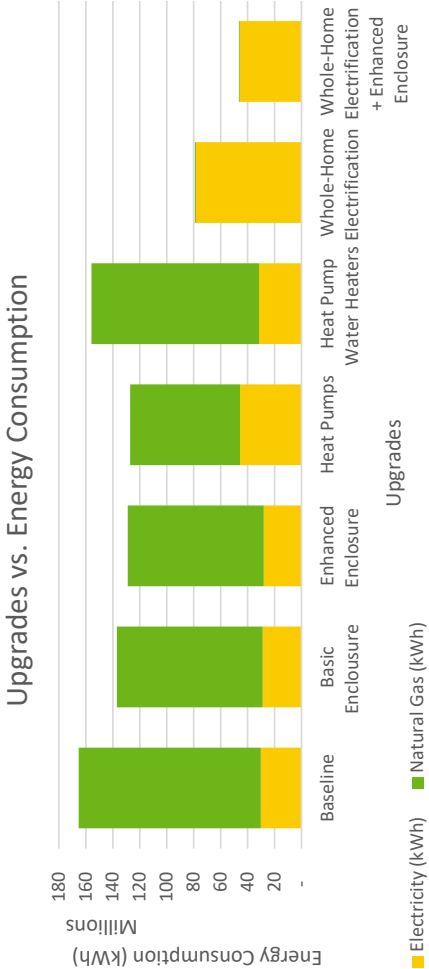
Baseline Emissions



# Home Energy Improvements

## Modeled Energy Upgrades in Highland Park, Michigan

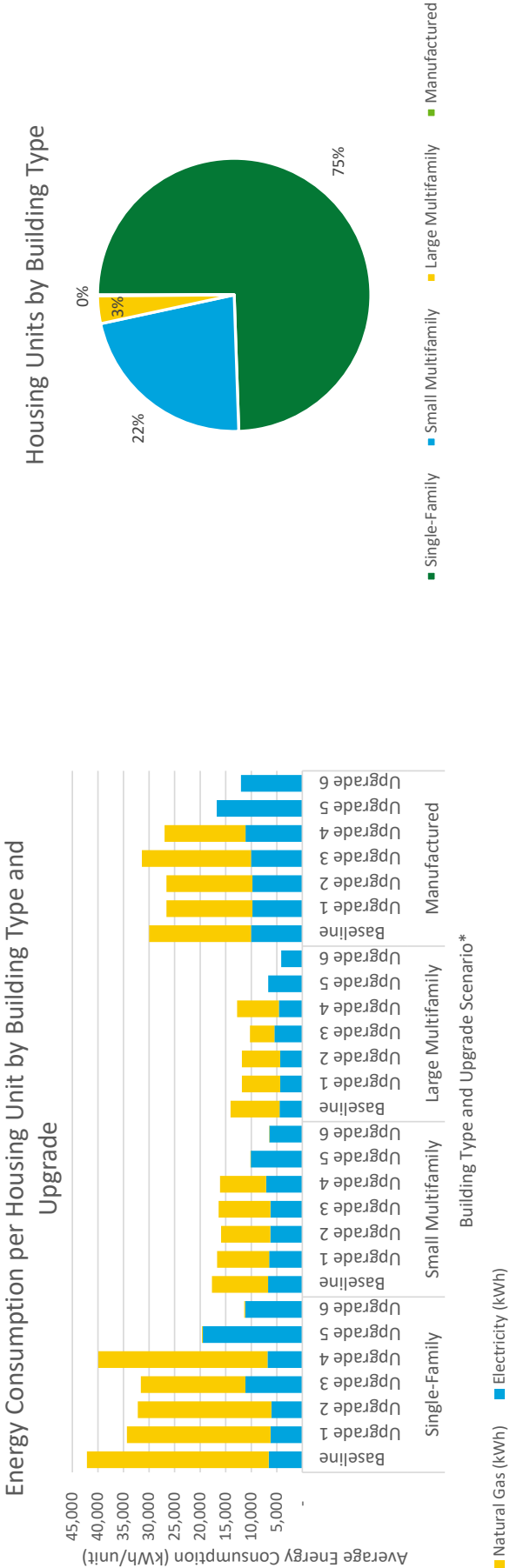
- Baseline and six upgrade scenarios:
  - Upgrade 1: Basic Enclosure (attic floor insulation, general air sealing, duct sealing, and wall insulation)
  - Upgrade 2: Enhanced Enclosure (Basic Enclosure, insulation for foundation wall and attic ceilings)
  - Upgrade 3: Electric Heat Pumps for Space Conditioning
  - Upgrade 4: Electric Heat Pump Water Heaters
  - Upgrade 5: Whole-Home Electrification (electric heat pumps, heat pump water heaters, electric ranges, etc.)
  - Upgrade 6: Whole-Home Electrification and Enhanced Enclosure.



# Home Energy Improvements

Based on the modeled data for the potential upgrade measures in Highland Park, Michigan:

- Single-family homes saw the largest percent decrease in total energy consumption for both envelope upgrades (Upgrades 1 and 2).
- Large multifamily homes saw the largest percent decrease in total energy consumption for both the heat pump for space conditioning (Upgrade 3) and the heat pump water heater upgrades (Upgrade 4).
- Single-family and large multifamily homes each saw a 57% total energy consumption decrease due to whole-home electrification (Upgrade 5).

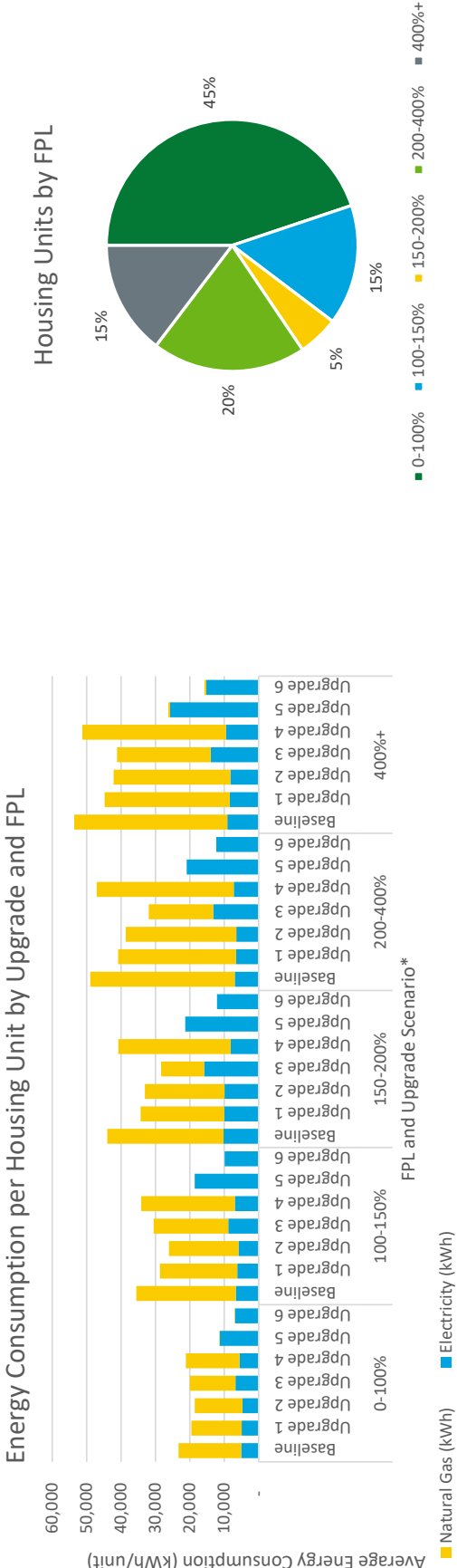




# Home Energy Improvements

Based on the modeled data for the potential upgrade measures in Highland Park, Michigan:

- 100%–200% FPL homes saw the largest percent decrease in total energy consumption for both envelope upgrades (Upgrades 1 and 2).
- 150–200% FPL homes saw the largest percent decrease in total energy consumption for the heat pump for space conditioning upgrade (Upgrade 3).
- 0–100% FPL homes saw the largest percent decrease in total energy consumption for the heat pump water heater upgrade (Upgrade 4).
- 200–400% FPL homes saw a 57% total energy consumption decrease due to whole-home electrification (Upgrade 5). All home types saw a 50% or better total reduction in home energy use.

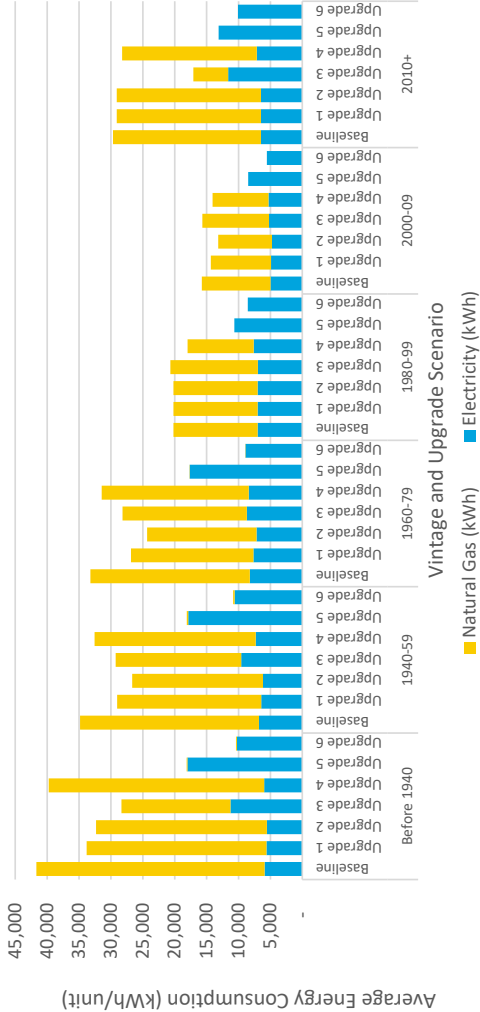


# Home Energy Improvements

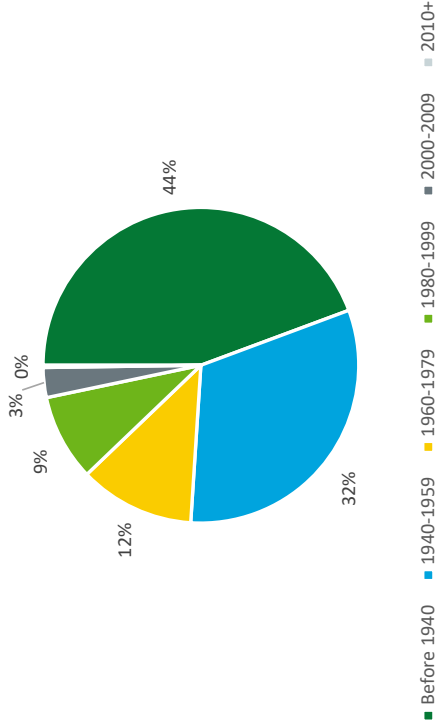
Based on the modeled data for the potential upgrade measures in Highland Park, Michigan:

- Homes built from 1960–1979 saw the largest percent decrease in total energy consumption for both envelope upgrades (Upgrades 1 and 2).
- Homes built after 2010 saw the largest percent decrease in total energy consumption for the heat pump for space conditioning (Upgrade 3).
- Homes built before 1940 saw the largest percent decrease in total energy consumption for the heat pump water heater upgrade (Upgrade 4).
- Homes built before 1940 and after 2010 saw a 56% total energy consumption decrease due to whole-home electrification (upgrade 5).

Energy Consumption per Housing Unit by Upgrade and Vintage



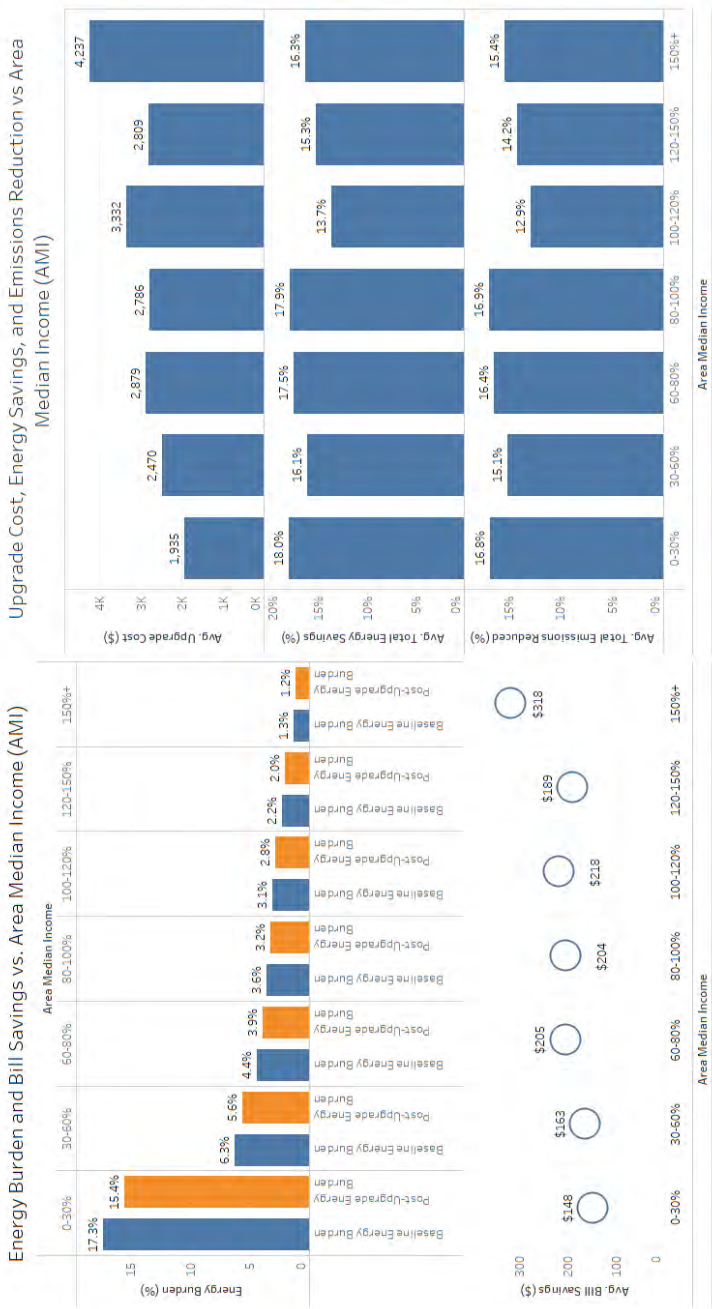
Housing Unit Counts by Vintage



# Basic Enclosure Upgrades

## For the modeled upgrade measures in Highland Park, Michigan:

- The Basic Enclosure package includes upgrading attic floor insulation, general air sealing, duct sealing, and wall insulation.
- For the basic enclosure upgrade, every area median income (AMI) group sees a decrease in energy burden, energy bill price, energy consumption, and emissions.
- The bill savings are around 10% for all AMI groups.
- The largest reduction in average energy burden happens in the 0–30% AMI group with the basic enclosure upgrade.

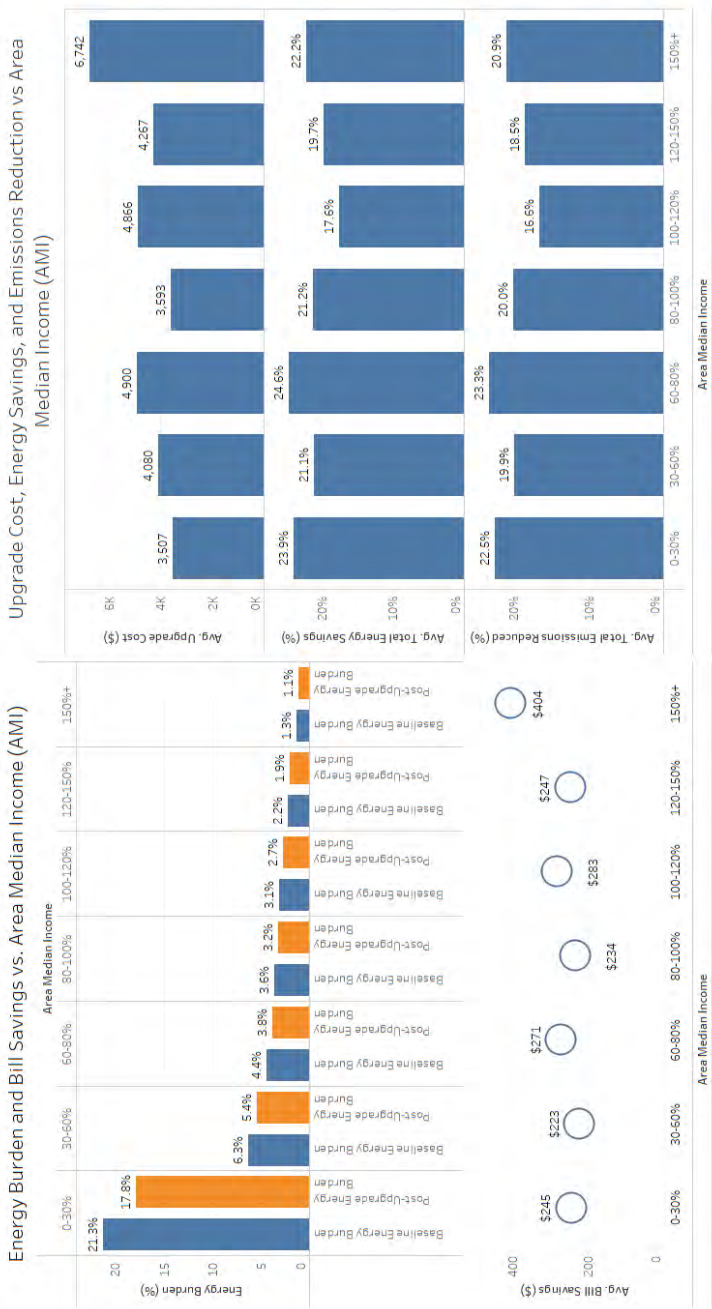


- All numbers are per housing unit by AMI category.
- All upgrade costs are national averages. They do not reflect local market conditions such as labor rates and do not include rebates.
- Assumed performance of upgrade measures are summarized in Appendix 1; performance may vary substantially for upgrades to specific individual housing units and may change over time.
- Bill impacts of electrification see increased spending on electricity and decreased gas spending.
- For emissions calculations, the grid prime energy mix is based on 2022 and will significantly change by 2035 based on the July 2023 settlement case.

# Enhanced Enclosure Upgrades

## For the modeled upgrade measures in Highland Park, Michigan:

- The Enhanced Enclosure package includes all upgrades in the Basic Enclosure package, interior insulation for foundation wall, and insulation for attic ceilings.
- For the enhanced enclosure upgrade, every AMI group sees a decrease in energy burden, energy bill price, energy consumption, and emissions.
- The bill savings are around 11–14% for all AMI groups.
- The largest reduction in average energy burden happens in the 0–30% AMI group with the enhanced enclosure upgrade.



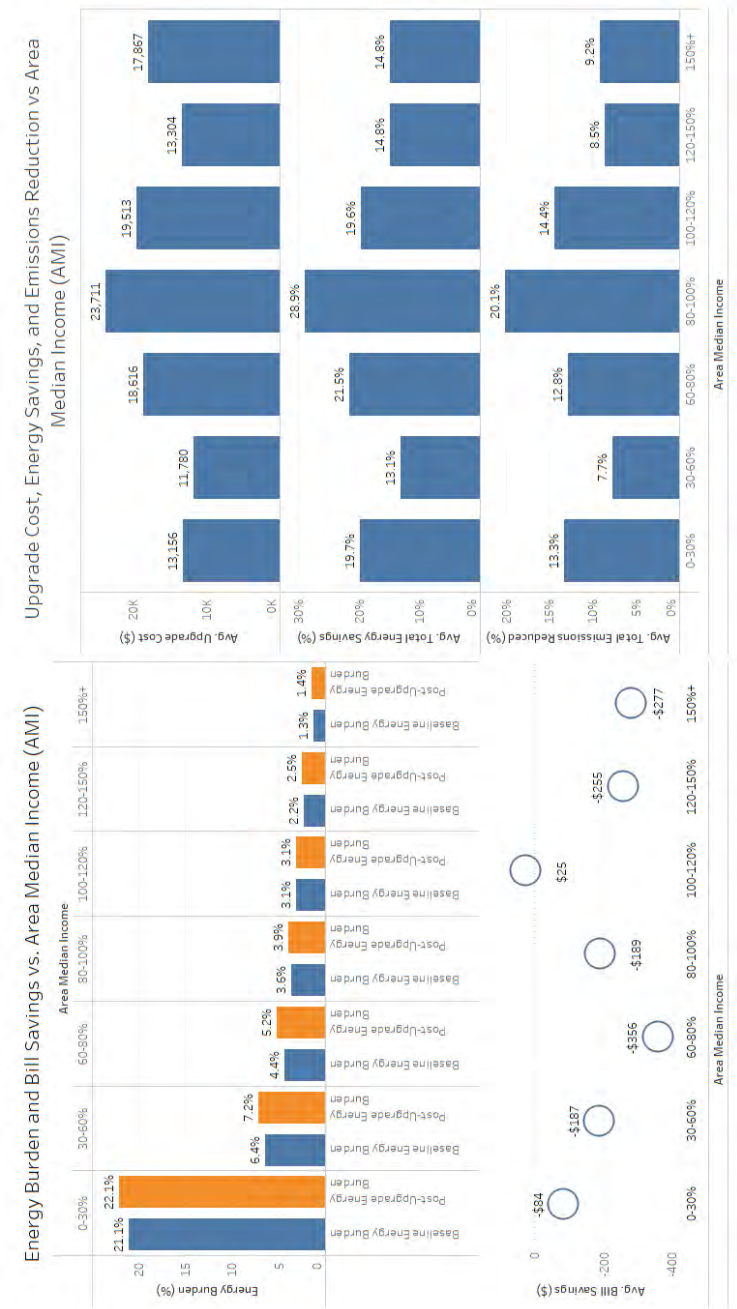
- All numbers are per housing unit by AMI category.
- All upgrade costs are national averages. They do not reflect local market conditions such as labor rates and do not include rebates.
- Assumed performance of upgrade measures are summarized in Appendix 1; performance may vary substantially for upgrades to specific individual housing units and may change over time.
- Bill impacts of electrification see increased spending on electricity and decreased gas spending.
- For emissions calculations, the grid prime energy mix is based on 2022 and will significantly change by 2035 based on the July 2023 settlement case.



# Electric Heat Pumps for Space Conditioning Upgrades

For the modeled upgrade measures in Highland Park, Michigan:

- The Electric Heat Pumps package includes upgrading natural gas or propane heating ventilation and air conditioning (HVAC) units with electric units.
- Energy savings and emissions reductions are seen across all AMI groups. However, energy bills generally do not decrease and therefore most AMI groups see an increase in energy burden.
- The bill increase is anywhere from 5%–20% for all AMI groups.
- The largest increase in average energy burden happens in the 0-30% AMI group.

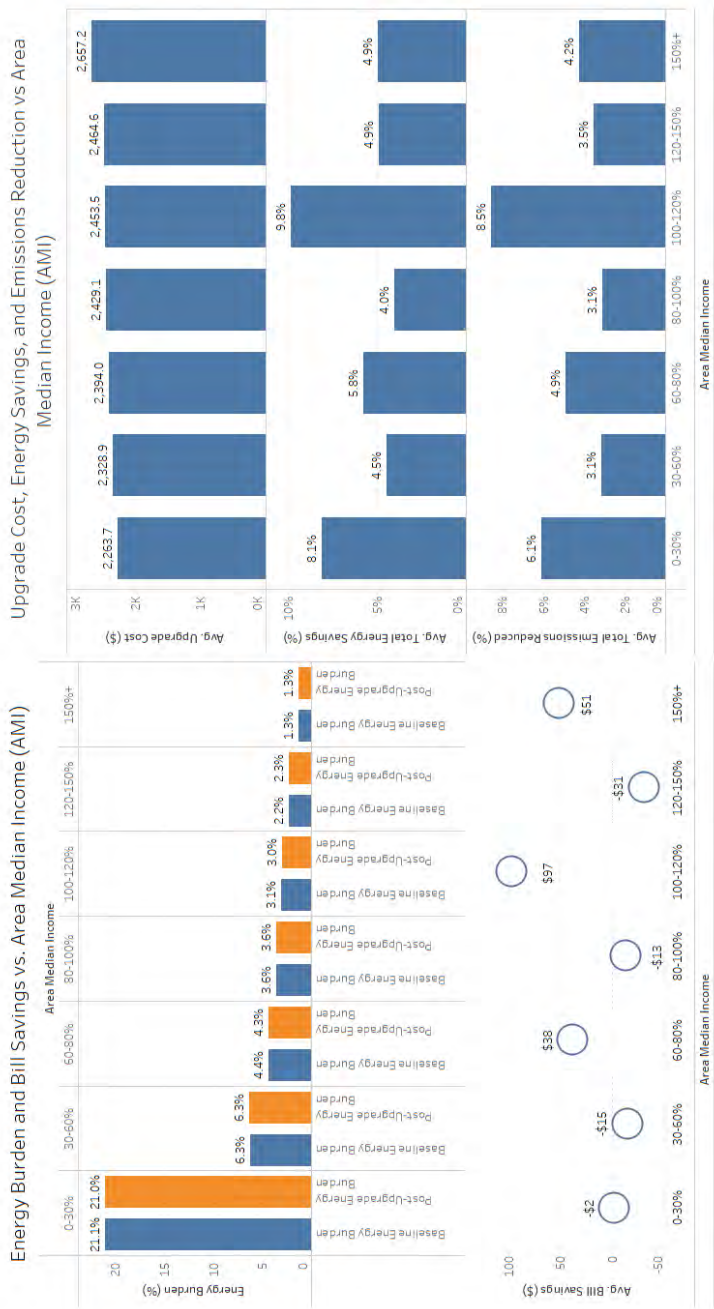


- All numbers are per housing unit by AMI category.
- All upgrade costs are national averages. They do not reflect local market conditions such as labor rates and do not include rebates.
- Assumed performance of upgrade measures are summarized in Appendix 1; performance may vary substantially for upgrades to specific individual housing units and may change over time.
- Bill impacts of electrification see increased spending on electricity and decreased gas spending.
- For emissions calculations, the grid prime energy mix is based on 2022 and will significantly change by 2035 based on the July 2023 settlement case.

# Electric Heat Pump Water Heaters Upgrades

## For the modeled upgrade measures in Highland Park, Michigan:

- The Electric Water Heaters package includes upgrading natural gas or propane water heating units with heat pump water heaters.
- Energy savings and emissions reductions are seen across all AMI groups. However, energy bills and thus energy burden generally see a mix of small increases or decreases across the AMI groups.
- The bill savings/increases are anywhere between a 3% savings and a 1.5% increase.
- This package includes an electrification measure, which generally increase spending on electricity while decreasing spending on gas.



- All numbers are per housing unit by AMI category.
- All upgrade costs are national averages. They do not reflect local market conditions such as labor rates and do not include rebates.
- Assumed performance of upgrade measures are summarized in Appendix 1; performance may vary substantially for upgrades to specific individual housing units and may change over time.
- Bill impacts of electrification see increased spending on electricity and decreased gas spending.
- For emissions calculations, the grid prime energy mix is based on 2022 and will significantly change by 2035 based on the July 2023 settlement case.

# Whole-Home Electrification Upgrades (No Enclosure Upgrades)

For the modeled upgrade measures in Highland Park, Michigan:

- The Whole-Home Electrification package includes heat pumps, heat pump water heaters, electric dryers, and an electric range. No change in enclosure is modeled for this package.
- Energy savings and emissions reductions are seen across all AMI groups. However, energy bills increase substantially for all groups. The 0–30% AMI groups see the smallest increase in energy bills (6%).
- The bill increases ranges from 28%–55%.



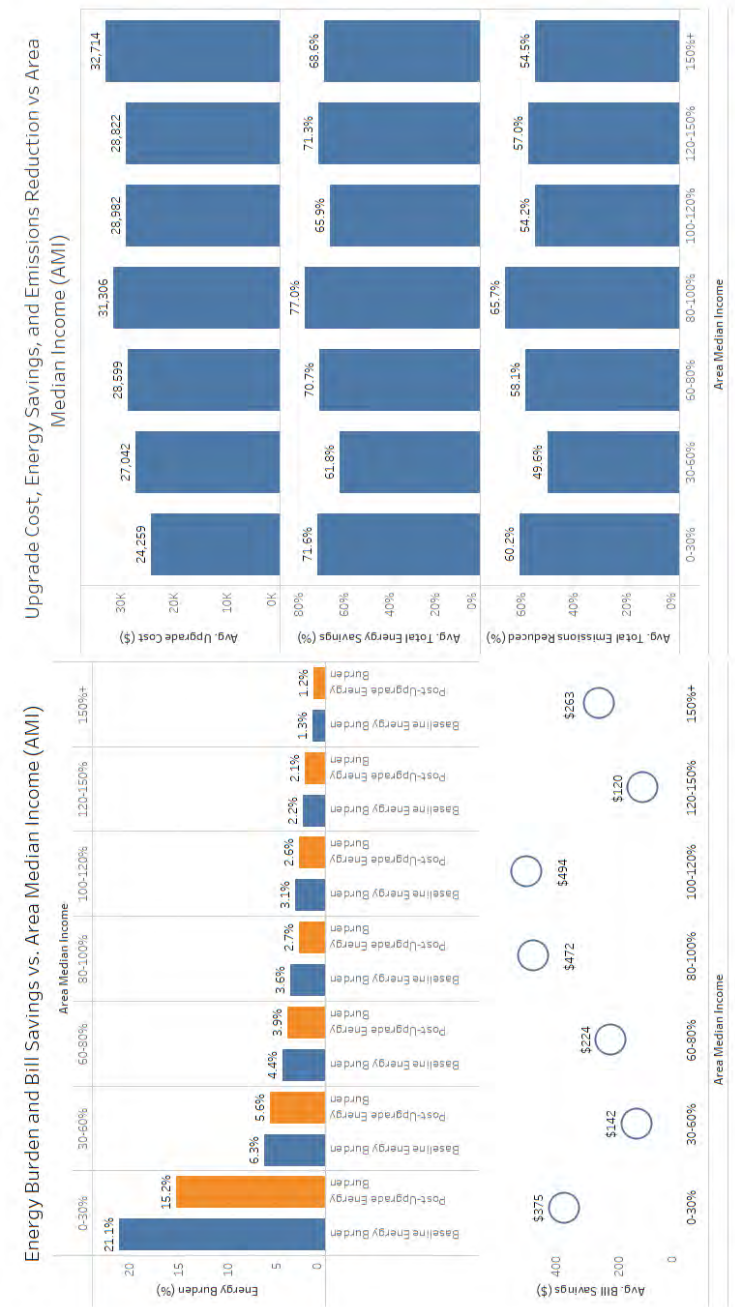
- All numbers are per housing unit by AMI category.
- All upgrade costs are national averages. They do not reflect local market conditions such as labor rates and do not include rebates.
- Assumed performance of upgrade measures are summarized in Appendix 1; performance may vary substantially for upgrades to specific individual housing units and may change over time.
- Bill impacts of electrification see increased spending on electricity and decreased gas spending.
- For emissions calculations, the grid prime energy mix is based on 2022 and will significantly change by 2035 based on the July 2023 settlement case.



# Whole-Home Electrification and Envelope Upgrades

## For the modeled upgrade measures in Highland Park, Michigan:

- The Whole-Home Electrification and Envelope package includes heat pumps, heat pump water heaters, electric dryers, and an electric range. The enclosure upgrades are the enhanced enclosure upgrades.
- For the electrification and enclosure upgrade, every AMI group sees a decrease in energy burden, energy bill price, energy consumption, and emissions.
- The bill savings are 10–23% for all AMI groups.
- The largest reduction in average energy burden happens in the 0–30% AMI group.



- All numbers are per housing unit by AMI category.
- All upgrade costs are national averages. They do not reflect local market conditions such as labor rates and do not include rebates.
- Assumed performance of upgrade measures are summarized in Appendix 1; performance may vary substantially for upgrades to specific individual housing units and may change over time.
- Bill impacts of electrification see increased spending on electricity and decreased gas spending.
- For emissions calculations, the grid prime energy mix is based on 2022 and will significantly change by 2035 based on the July 2023 settlement case.



# Key Findings

Based on the modeled upgrade measures in Highland Park, Michigan:

- For both **enclosure** upgrade scenarios presented, the energy consumption, energy-related emissions, energy burden, and energy bills all decreased.
- The **electric heat pump** upgrade provides energy savings and emissions reductions. However, energy bills generally do not decrease and therefore most AML groups see an increase in energy burden.
- The **heat pump water heater** upgrade measure delivers energy and emissions savings while energy bills remain close to the same and therefore energy burden slightly changes as well.
- The **whole-home electrification with no envelope** upgrade measure provides energy savings and emissions reductions. This measure does not provide any reduction to energy bills, so the energy burden increases as well.
- The **whole-home electrification with the enhanced envelope** upgrade measure package provides energy savings, emissions reductions, energy bills savings, and a reduction to energy burden.
- The analysis highlighted that doing a **whole-home electrification with an enhanced envelope** upgrade has the highest impact followed by the individual **enclosure** upgrades and the **heat pump water heater** upgrade.

# Community Coalition Interpretation of Findings

After discussion with the community coalition, they interpreted the results on the previous slides in the following manner.

- Due to the current utility energy mix and electricity costs, prioritizing the improvement of building envelopes would provide the best benefit to community members due to reductions in energy consumption, emissions, energy bills, and energy burden. Also discussed was that as you improve the energy efficiency of the buildings, they will likely see better benefits from electrification.
- Heat pump water heater upgrades would be the first electrification measure to be considered by the community. This is due to the modeled results showing that this measure delivers energy and emissions savings while energy bills remain close to the same.
- Finally, the community would focus on electric heat pumps. While heat pump upgrades did not show a reduction in energy bill and energy burden when applied on their own, by completing heat pump upgrades, heat pump water heater upgrades, and enclosure upgrades, houses will have had a similar upgrade package to the whole-home electrification with an envelope upgrade and will see similar benefits to that upgrade scenario.
- The community discussed that with these upgrades they would eventually see long-term benefits of decreased electricity consumption, decreased energy emissions, and reduced bill costs.



# Thank You

[www.energy.gov/communitiesLEAP](http://www.energy.gov/communitiesLEAP)

Produced for the U.S. Department of Energy  
by the National Renewable Energy Laboratory (NREL).  
DOE/GO-102024-6090 • March 2024



# Appendix I

Upgrades



# Appendix I

|                                                  |
|--------------------------------------------------|
| Basic Enclosure Upgrades                         |
| Enhanced Enclosure Upgrades                      |
| Heat Pump Upgrades                               |
| Electric Water Heater Upgrades                   |
| Whole-Home Electrification Upgrades              |
| Whole-Home Electrification and Envelope Upgrades |

|                        |                                                                                                                                                                                                                                                                                                                                               |
|------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Attic Floor Insulation | <ul style="list-style-type: none"><li>• International Energy Conservation Code levels</li><li>• R-30 for homes in Climate Zone 1A with <math>\leq</math> R-13</li><li>• R-49 for homes in Climate Zones 21, 2B, 3A, 3B, 3C with <math>\leq</math> R-30</li><li>• R-60 for homes in other climate zones with <math>\leq</math> R-38.</li></ul> |
| General Air Sealing    | <ul style="list-style-type: none"><li>• 30% total reduction in Air Changes per Hour</li><li>• Applied to homes with greater than 10 ACH<sub>50</sub>.</li></ul>                                                                                                                                                                               |
| Duct Sealing           | <ul style="list-style-type: none"><li>• Ducts improved to 10% leakage, R-8 insulation</li><li>• Applied to homes with leakier or less-insulated ducts.</li></ul>                                                                                                                                                                              |
| Wall Insulation        | <ul style="list-style-type: none"><li>• R-13 drill-and-fill insulation</li><li>• Applied to homes with wood stud walls and no insulation.</li></ul>                                                                                                                                                                                           |

# Appendix I

|                                                  |
|--------------------------------------------------|
| Basic Enclosure Upgrades                         |
| Enhanced Enclosure Upgrades                      |
| Heat Pump Upgrades                               |
| Electric Water Heater Upgrades                   |
| Whole-Home Electrification Upgrades              |
| Whole-Home Electrification and Envelope Upgrades |

Everything in the *Basic Enclosure package*



Foundation Wall and Rim Joist Insulation

- Add R-10 interior insulation to foundation walls and rim joists
- Seal crawlspace vents.

Finished Attic and Cathedral Ceiling Insulation

- Insulate finished attics and cathedral ceilings to R-30.



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| Whole-Home Electrification and Envelope Upgrades |

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <div>Heat Pump</div> <div>Seasonal energy efficiency ratio (SEER) 15, 9 heating seasonal performance factor (HSPF), conventional centrally-ducted for homes with ducts and a ductless mini-split heat pump SEER 15, 9 HSPF.</div>                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <div>Backup Heating</div> <div>Baseline non-ducted heating:<ul style="list-style-type: none"><li>Existing heating system retained as backup</li><li>Backup system used when heat pump cannot meet the load.</li></ul>Baseline ducted non-electric heating:<ul style="list-style-type: none"><li>Existing heating system retained as backup</li><li>Switchover temperature of 41°F<ul style="list-style-type: none"><li>Heat pump used above</li><li>Backup used below.</li></ul></li></ul>Baseline ducted electric heating:<ul style="list-style-type: none"><li>Electric resistance backup</li><li>Backup system used when heat pump cannot meet the load.</li></ul></div> |

# Appendix I

|                                                  |
|--------------------------------------------------|
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| Electric Water Heater Upgrades                   |
| Whole-Home Electrification Upgrades              |
| Whole-Home Electrification and Envelope Upgrades |

50-Gallon, 3.45 Uniform Energy Factor (UEF) Heat Pump Water Heater

- For one- to three-bedroom homes.

66-Gallon, 3.35 UEF Heat Pump Water Heater

- For four-bedroom homes.

80-Gallon, 3.45 UEF Heat Pump Water Heater

- For greater than four-bedroom homes.

# Appendix I

|                                                  |
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| Whole-Home Electrification and Envelope Upgrades |

| Homes with Non-Electric... | Receive                                                                                           |
|----------------------------|---------------------------------------------------------------------------------------------------|
| Heating                    | Minimum-efficiency heat pump and electric resistance backup heat as listed in Heat Pump Upgrades. |
| Water heating              | Heat pump water heater from measure package for heat pump water heaters.                          |
| Dryer                      | Electric resistance dryer.                                                                        |
| Cooking                    | Electric range and oven.                                                                          |

- No enclosure measures.
  - No change to existing electric loads.

# Appendix I

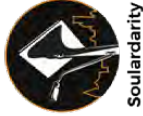
|                                                  |
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| Whole-Home Electrification and Envelope Upgrades |

## Enhanced Enclosure Upgrades

- Attic floor insulation.
- Air sealing.
- Duct sealing.
- Drill-and-fill wall insulation.
- Foundation wall and rim joist insulation.
- Finished attic and cathedral ceiling insulation.

## Whole-Home Electrification Upgrades

- Heat pump.
- Heat pump water heater.
- Ventless heat pump dryer.
- Induction range and electric oven.



# Distribution Grid Impact Study in Highland Park, Michigan

## Understanding Rooftop Solar, Behind-the-Meter Energy Storage, Electric Vehicle Charging, and Building Electrification

Erik Pohl, Kapil Duwadi, Tucker Oddleifson, Shibani Gosh, Vignesh Ramasamy, Patrick Gibbs  
National Renewable Energy Laboratory

March 2024

# Notice

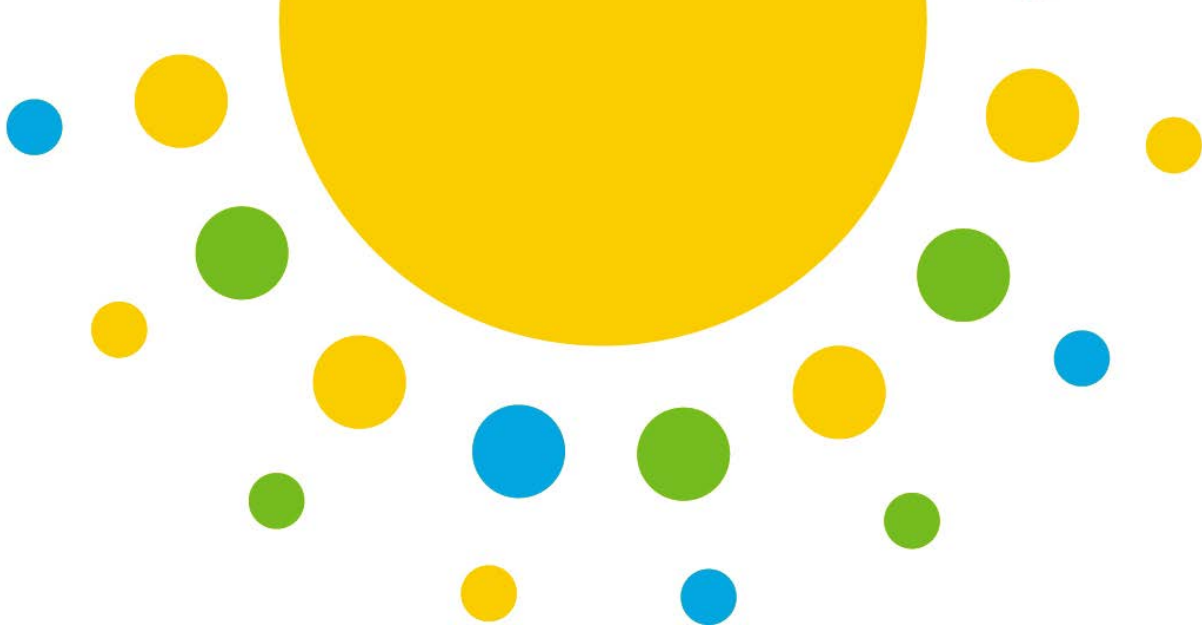
*This work was authored by the National Renewable Energy Laboratory (NREL), operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the DOE's Communities LEAP (Local Energy Action Program) Pilot.*

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## Slide Deck Contents

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- 1** Project Overview and Key Takeaways
- 2** Methods of Analysis
- 3** Scenario Analysis Results
- 4** Estimate of Upgrade Costs



# Terminology

- **Current Model:** Distribution circuit load flow model reflecting the current design, construction, and voltage class (4.8 kV).
- **DER:** Distributed energy resource, defined by the Federal Energy Regulatory Commission (FERC) as follows: “DERs are small-scale power generation or storage technologies (typically from 1 kW to 10,000 kW) that can provide an alternative to or an enhancement of the traditional electric power system. These can be located on an electric utility’s distribution system, a subsystem of the utility’s distribution system or behind a customer meter. They may include electric storage, intermittent generation, distributed generation, demand response, energy efficiency, thermal storage or electric vehicles and their charging equipment.”<sup>1</sup>
- **Primary Line:** Medium voltage overhead wire or underground cable.
- **SARDI:** System average risk duration index measuring the sum of customers hours impacted by voltage and thermal violations and normalized by total customer hours (expressed as a percentage).
- **Secondary Line:** Low-voltage overhead wire or underground cable. Secondary Lines may be connected directly to the low-voltage side of the service transformer or may be connected to other secondary lines in a network and may serve one or more customers.
- **Service Drop:** Low-voltage overhead wire or underground cable, directly connected to a customer’s house. A service drop generally serves only one customer.
- **Transformer:** A power systems device to convert, in our models, medium voltage (e.g., 4.8 or 13.2 kV) down to low voltage (e.g., 120/240V). This represents the transition point from the primary distribution network to the secondary distribution network. A transformer may serve one or many individual customers.
- **Upgraded Model:** Distribution circuit load flow model reflecting the likely future design, construction and voltage class (13.2 kV), per the recommendations of DTE engineers.

<sup>1</sup> “FERC Order No. 2222: Fact Sheet.” 2020. Federal Energy Regulatory Commission. September 17, 2020. <https://www.ferc.gov/media/ferc-order-no-2222-fact-sheet>.

# Project Overview

# Communities LEAP Scoping Context

Through the Communities LEAP (Local Energy Action Program) Pilot, the National Renewable Energy Laboratory (NREL) engaged the Highland Park Stakeholder Coalition to scope four technical assistance work areas to address their energy needs and goals.

This slide deck addresses the highlighted tasks under work area “B.”

| A . City-Wide Solar Street Lighting and Policy Analysis                                                                                                                                                                                                                                                                                 | B. Grid Analysis                                                                                                                                                                                                                                                                                                                                 | C. Community Choice: Home Energy Improvements                                                                                                                                | D. Bonus Bucket! Transportation and Mobility with MCC                                                                                                                      |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"><li>Task 1: Solar Street Lighting Financial Model Review</li><li>Task 2: Due Diligence References</li><li>Task 3: Implemented Case Studies</li><li>Task 4: Master Plan Gap Analysis</li><li>Task 5: Zoning Code + Applications Gap Analysis</li><li>Task 6: Review Proposed Solar Ordinance</li></ul> | <ul style="list-style-type: none"><li>Task 1: Determine Existing Load Profile + Feeder Model (reference case)</li><li>Task 2: Grid Analysis (limitations and capacity under three growth scenarios)</li><li>Task 3: Feasibility Analysis 3 Actionable Behind Meter Projects (within City’s authority under current grid configuration)</li></ul> | <ul style="list-style-type: none"><li>Task 1: Support a coalition-facilitated selection process</li><li>Task 2: Housing Characteristics and Energy Burden Analysis</li></ul> | <ul style="list-style-type: none"><li>Task 1: Coordinate with Michigan Clean Cities on feasibility study for Perimeter Loop micro-mobility utilizing EV shuttles</li></ul> |

# Project Context

Highland Park, Michigan, community members face frequent, long-duration power interruptions due largely to the aging distribution system serving the area and the legacy design standards used in its construction.

While degrading physical infrastructure such as poles, crossarms, and transformers can result in this substandard reliability, another notable characteristic of this legacy system is the lower, 4.8 kV, voltage class. This is a legacy construction standard which many utilities, DTE Energy included, are phasing out in favor of higher, 15 or 25 kV, voltage classes instead.<sup>1</sup> The existing 4.8 kV distribution system serving Highland Park may limit significant adoptions of clean-energy technologies like high percentages of building electrification or electric vehicle (EV) adoption.

The following analysis seeks to quantify these limitations under a variety of clean-energy technology adoption scenarios. It compares the overall system risks of the present system to those of a hypothetical, upgraded 13.2 kV system, using NREL-developed risk metrics and offers upgrade cost considerations.

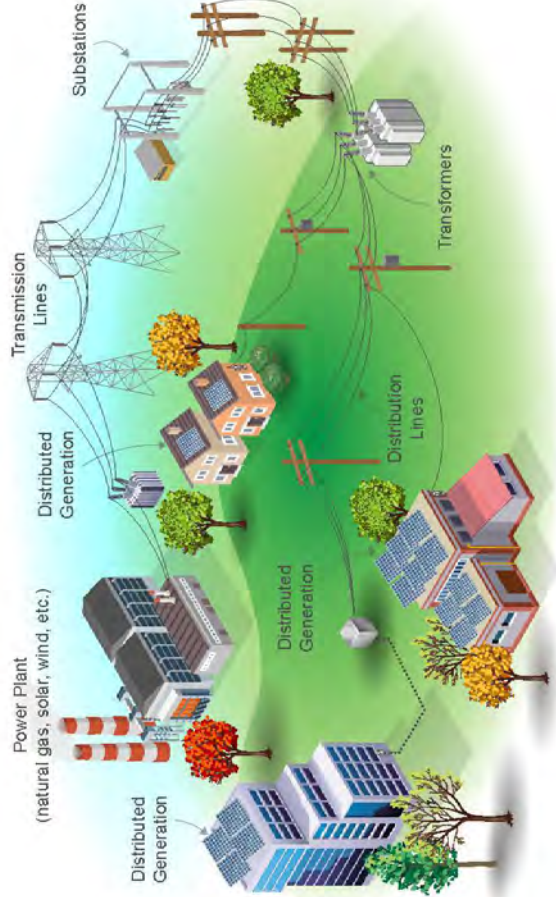
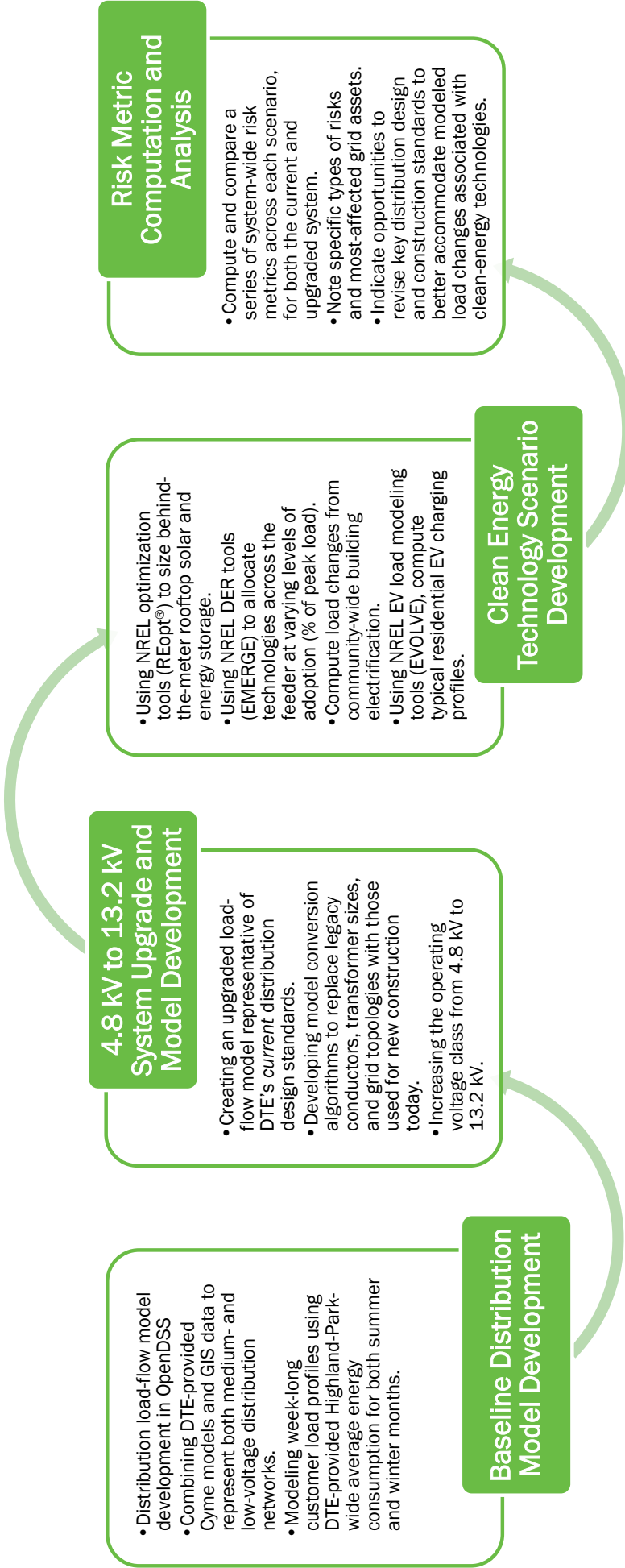


Illustration of the “grid” from utility power plant, transmission, distribution, to distributed energy resources. Illustration by Alfred Hicks, NREL 65851

<sup>1</sup> Wang, Joy. “DTE Electric 4.8kV Technical Conference.” n.d. <https://www.michigan.gov/mpsc/consumer/electricity/dte-electric-4-8kv-technical-conference>.

# Project Approach: Understanding the Analysis

Using data provided by DTE, NREL modeled a typical distribution feeder in one of Highland Park’s mixed-use areas. This model was used to baseline and characterize typical vulnerabilities of the existing distribution grid and assess how it would perform under various load growth and distributed energy resource (DER) adoption scenarios. The results of this study compare the risks of the existing 4.8 kV grid to an upgraded 13.2 kV grid under changing loads due to electrification, EV charging adoption, and DER adoption.





# Key Takeaways

- **The System Today (Current Model):**

- o The legacy 4.8 kV voltage class serving Highland Park is not, as we have modeled it, a major limitation to the widespread adoption of cost-optimal\* rooftop solar and/or behind-the-meter energy storage. Within our modeling framework, these technologies namely impact secondary, low-voltage assets, which may be remedied without the need for a system-wide upgrade to a 13.2 kV voltage class.
- o Our model of the current 4.8 kV system indicates it is not capable of supporting community-wide electrification efforts. Widespread building electrification, and the resulting large increase in wintertime load, dramatically increases the prevalence of voltage violations and thermal overloading on the current 4.8 kV distribution system. These impacts illustrate the need for system-wide upgrades to a 13.2 kV voltage class to accommodate these technologies.
- o Low to Moderate DER adoption does not adversely impact the grid but does improve undervoltage and asset overloading issues. However, these benefits are insufficient to defer grid upgrades. Higher DER penetration is shown to increase overvoltage and asset overloading in future electrification scenarios.

- **The System of Tomorrow (Upgraded Model):**

- o In all cases, upgrading the system to a higher voltage class and using modern design standards significantly reduces system risks associated with the adoption of DERs or building electrification.
- o The persistent violations remaining on the upgraded system are largely concentrated in the low-voltage secondary networks and service transformers. This illustrates the need for more robust secondary design standards to accommodate the large increases in load. Such standards may include larger secondaries, service drops, and transformers, or serving fewer customers per transformer.
- o Further study is required to estimate the cost of system-wide upgrade needs specific to Highland Park. See slide 69 for cost considerations.

*\*Cost-optimal refers to the size of rooftop solar and/or energy storage systems which minimizes the financial burden on participating community members. This optimization was performed using NREL's REopt tool and is detailed in the accompanying slide deck.<sup>1</sup>*

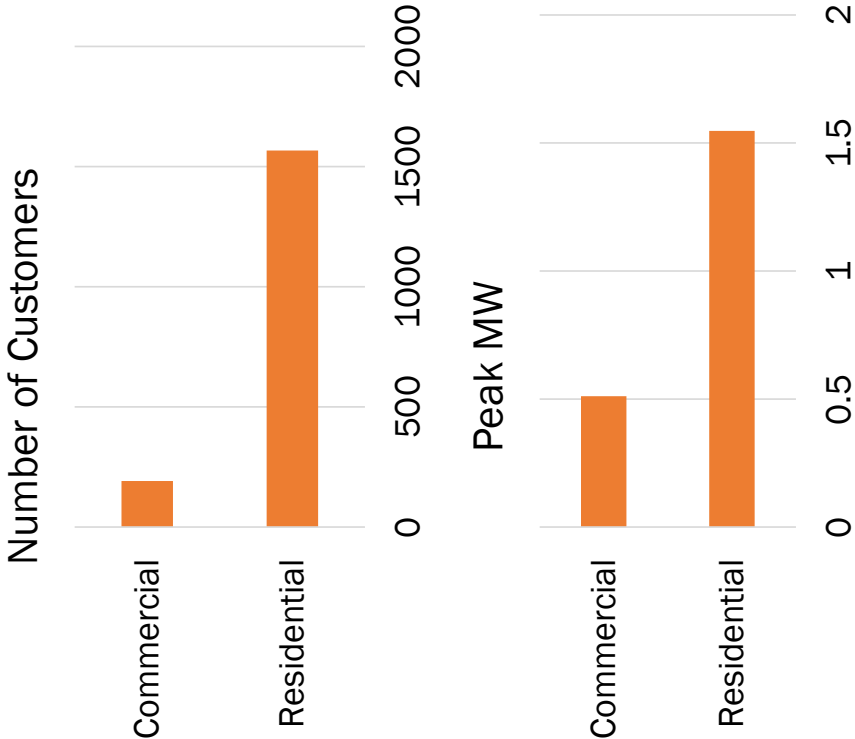
<sup>1</sup> Oddleifson, Tucker, Kapil Duwadi, Erik Pohl, Patrick Gibbs, Shibani Ghosh, Chrissy Scarpitti, and Liz Weber. 2024. "Prefeasibility Analysis of Behind-the-Meter Distributed Energy Resources in Highland Park, MI." February. <https://www.nrel.gov/docs/fy24osti/87988.pdf>.

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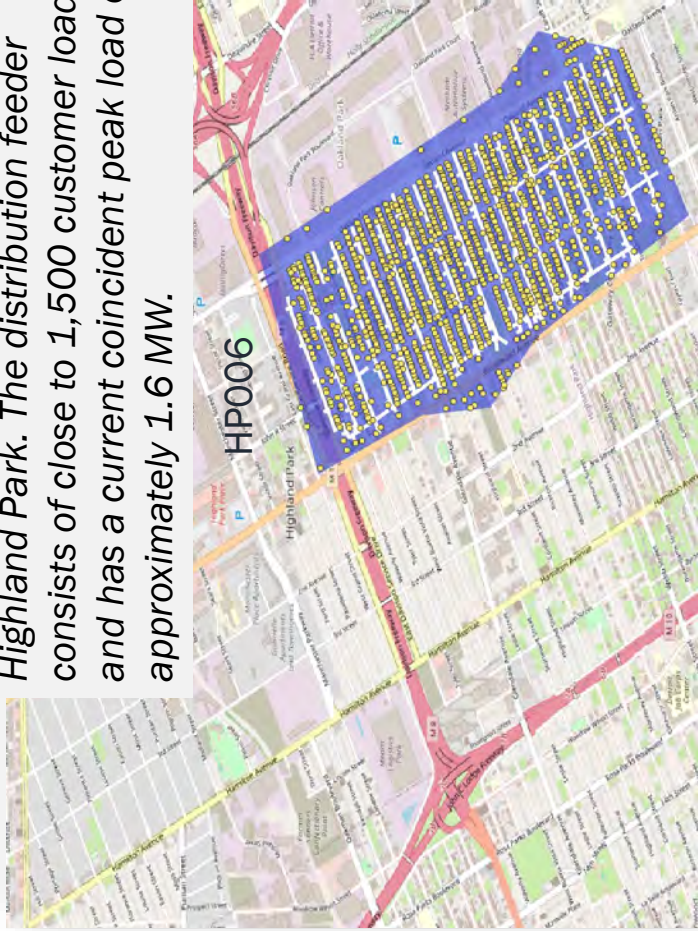
# Methods of Analysis



# Understanding the Grid As It Is – Location and Customer Class



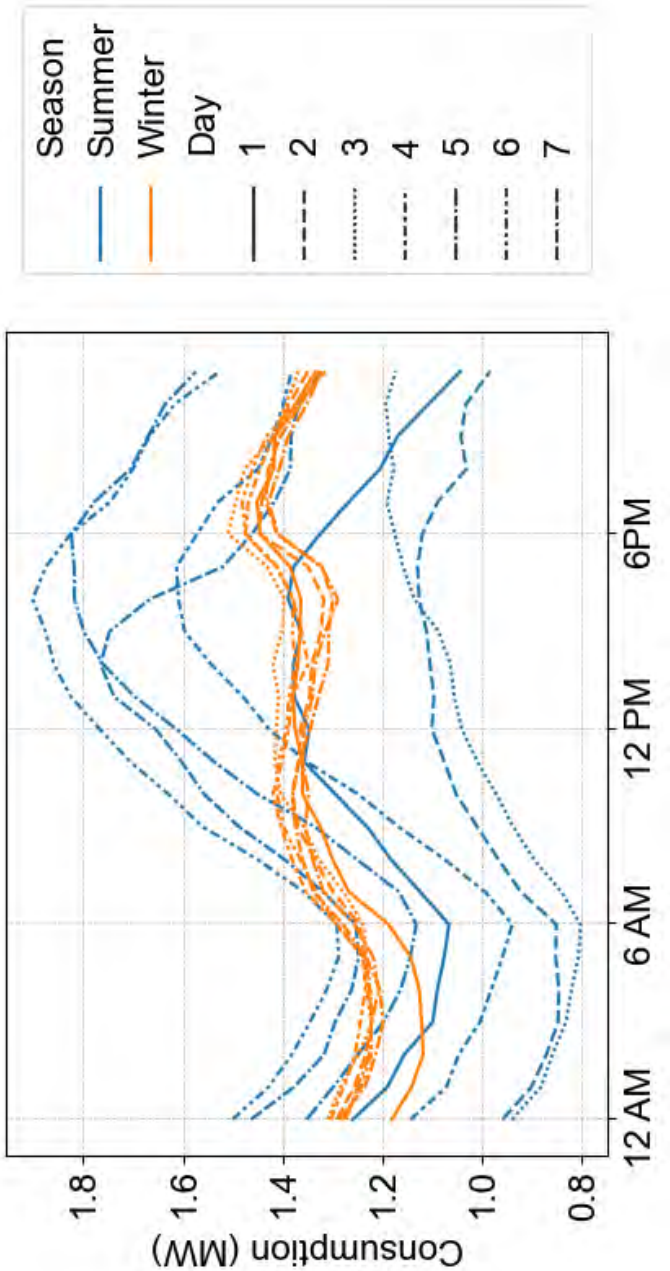
For this study, we looked at a mixed-use feeder (though majority residential) within Highland Park. The distribution feeder consists of close to 1,500 customer loads and has a current coincident peak load of approximately 1.6 MW.



Model includes only a portion of Highland Park

# Understanding the Grid As It Is – Seasonal Load Profiles

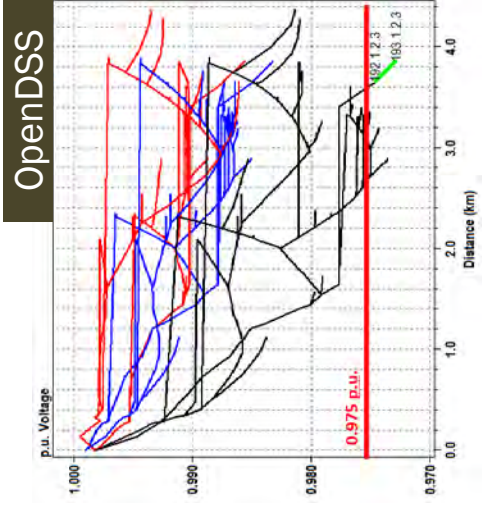
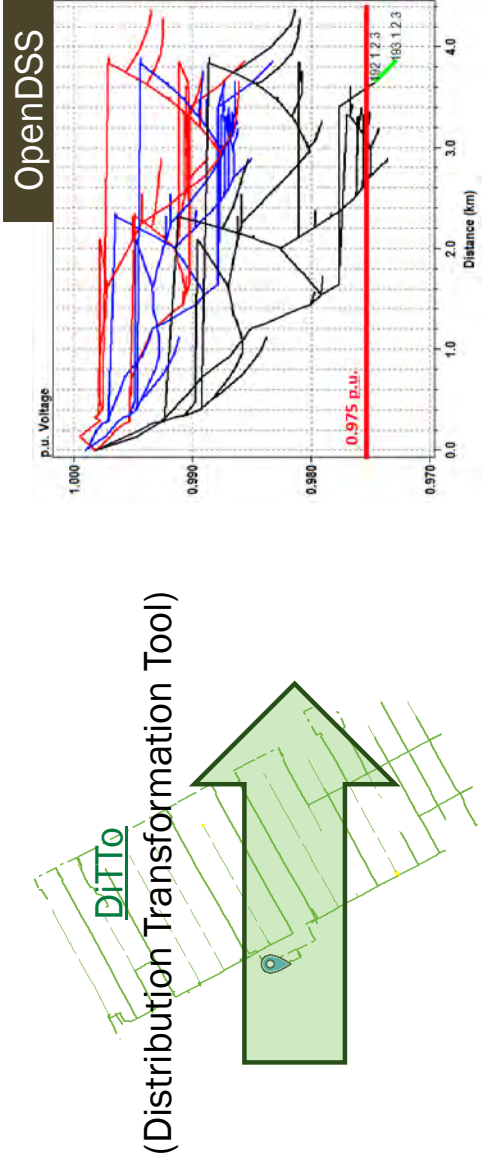
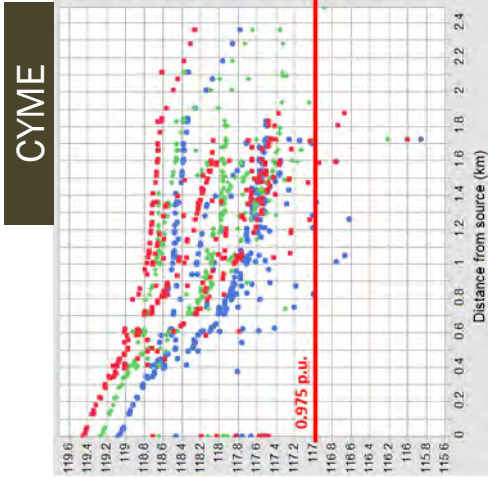
We used average timeseries load consumption data (also known as load profiles) for residential and commercial customer groups provided by [DTE Energy](#) as an input to our timeseries power flow analysis. To understand the grid impacts under the various scenarios described in later slides, we looked at weeklong simulation results for a summer and winter peak consumption week. The resulting load profiles, shown here, illustrate that during our summer week, the system generally sees peak load in the afternoon to early evening, while winter days more consistently peaked around 6 to 7 p.m.



\*Summer Week: July 1–July 7, Winter Week: Feb. 5–Feb. 11

# Understanding the Grid As It Is – Distribution System Model

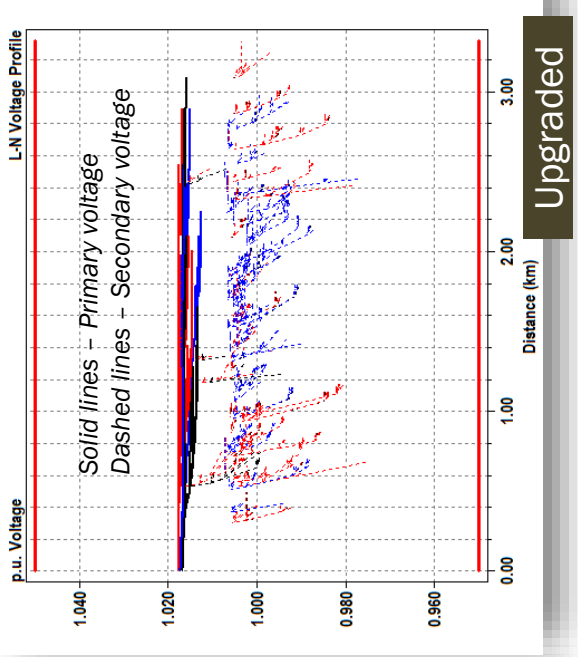
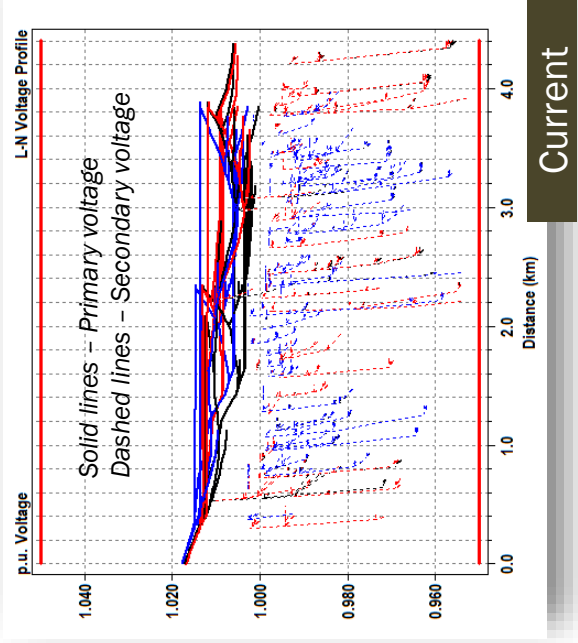
The first step of our analysis was to convert the DTE-provided load flow model of a Highland Park feeder to a format compatible with NREL’s analysis tools. The model was provided in the format used by [Eaton’s CYME](#) distribution modeling software. Using an NREL-developed software called DiTTo (Distribution Transformation Tool), we converted this model to be analyzed in the open-source tool, [OpenDSS](#), developed by the Electric Power Research Institute (EPRI). The provided CYME model also contained only information of the medium-voltage distribution network, with no depiction of the low-voltage secondary networks, serving individual customers. As such, we leveraged DTE-provided GIS data depicting the topology of these networks and [Microsoft’s opensource parcel](#) data to add these missing components to the feeder model.



# Upgrading the Grid – Current and Upgraded Models

|                | Primary Backbone                                              | Secondary Main                            | Service Drop  | Transformers                                        |
|----------------|---------------------------------------------------------------|-------------------------------------------|---------------|-----------------------------------------------------|
| Current Model  | OH (4/0 Cu, #2 Cu, #4 Cu, #6 Cu)<br>UG (4/0 Cu, 450 kcmil Cu) | Open-wire 1/0 ACSR,<br>Open-wire 4/0 ACSR | #2 AL Triplex | Original sizes                                      |
| Upgraded Model | OH (636 Al, 1/0 ACSR)<br>UG (1000 kcmil AL, #2 AL)            | 1/0 AL Triplex,<br>4/0 AL Triplex         | #2 AL Triplex | <50 kVA TO 50 kVA<br>(31/112 Transformers Replaced) |

The table above lists the distribution assets that were replaced in our upgrade process. Another key characteristic of the Current Model was the presence of looped primary circuits (i.e., parallel paths from the source to loads, without any breakpoints). This is also a legacy design practice and was remedied in our Upgraded Model, by installing normally-open switches where loops exist, creating a truly radial distribution feeder topology.





# Understanding DER Impact: Scenarios

In all scenarios, the size of rooftop solar and energy storage systems are prescribed by NREL's [REopt software](#). The key assumptions used in this tool are explained in detail in the accompanying slide deck.<sup>1</sup>

NREL's [EMERGE](#) software is used to perform timeseries power flow analysis (summer and winter week) at 20%, 40%, 60%, 80% and 100% (% of peak load) adoption scenarios. Future electrification scenarios include electric heating as well as high efficiency appliances, and enclosures.

The table on the right shows all the scenarios and load multipliers used to size the solar and energy storage. For electric vehicles, a fixed charger size was used (1.2 kW for Level 1 and 7.6 kW for Level 2) assuming a mix of 20% Level 2 and 80% Level 1 chargers. The time-series load profiles for EVs are generated using NREL's [EVOLVE tool](#).

<sup>1</sup> Oddleifson, Tucker, Kapil Duwadi, Erik Pohl, Patrick Gibbs, Shibani Ghosh, Chrissy Scarpitti, and Liz Weber. 2024. "Prefeasibility Analysis of Behind-the-Meter Distributed Energy Resources in Highland Park, MI." February. <https://www.nrel.gov/docs/fy24osti/87988.pdf>.

| Analysis Scenarios<br>*Battery sizing is based on 24-hour outage survival resilience objective | PV Multiplier<br>(Res, Comm)<br>*multiplied with customer peak load (kW) to size PV | Battery Multiplier<br>(Res, Comm)<br>*multiplied with customer peak load (kW) to size battery |
|------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| Solar Only, Current Model, Base Electrification                                                | (0.547, 2.68)                                                                       | N/A                                                                                           |
| Solar + Battery, Current Model, Base Electrification                                           | (1.3088, 2.68)                                                                      | (0.93, 0.2625)                                                                                |
| Solar Only, Upgraded Model, Base Electrification                                               | (0.547, 2.68)                                                                       | N/A                                                                                           |
| Solar + Battery, Upgraded Model, Base Electrification                                          | (1.3088, 2.68)                                                                      | (0.93, 0.2625)                                                                                |
| Solar Only, Current Model, Future Electrification                                              | (0.2, 2.68)                                                                         | N/A                                                                                           |
| Solar + Battery, Current Model, Future Electrification                                         | (0.86, 2.68)                                                                        | (0.356, 0.2625)                                                                               |
| Solar Only, Upgraded Model, Future Electrification                                             | (0.2, 2.68)                                                                         | N/A                                                                                           |
| Solar + Battery, Upgraded Model, Future Electrification                                        | (0.86, 2.68)                                                                        | (0.356, 0.2625)                                                                               |
| Solar + Battery, Current Model, Future Electrification, Electric Vehicles                      | (0.86, 2.68)                                                                        | (0.356, 0.2625)                                                                               |
| Solar + Battery, Upgraded Model, Future Electrification, Electric Vehicles                     | (0.86, 2.68)                                                                        | (0.356, 0.2625)                                                                               |

## System Average Risk Duration Indices (SARDI): An Overview

- SARDI (System Average Risk Duration Indices) metrics define a system-level risk to quantify the impacts to system performance and reliability affecting customers.
  - SARDI metrics are analogous to the commonly-used reliability index SAIDI (System Average Interruption Duration Index).
- As suggested by the System Average prefix to SARDI, this approach calculates an average risk across all customers and all distribution assets.
- Voltage violations\* indicate customers or assets operating at a voltage that is outside of what the industry generally defines as acceptable thresholds. On U.S. power systems, these thresholds often align with the standard from the American National Standards Institute (ANSI), C84.1,<sup>1</sup> and is +/- 5% from nominal values.
- Thermal violations\* indicate an asset that has exceeded its rated capacity. This could be an overloaded overhead wire, underground cable, or transformers. These violations can occur on both the primary (medium-voltage) distribution assets, or the secondary (low-voltage) distribution assets.
- The risk on a circuit, as calculated using our SARDI approach, is determined by various factors including:
  - Depth of violation: e.g., 5% overloaded vs. 50% overloaded
  - Duration of violation: e.g., overloaded for 2 hours out of the year vs. 2 hours every day
  - Importance of asset: e.g., If this asset failed, how many customers would be affected? Generally, assets like wires and cables located nearer the substation serve larger numbers of customers and, as such, receive a higher weighting based on downstream customer count.

\*Unless otherwise stated, *grid impact in this study focuses only on voltage violations and thermal overloading of conductors and transformers.*<sup>2</sup>

<sup>1</sup> American National Standards Institute, Inc. 2016. "ANSI C84.1-2016: American National Standard for Electric Power Systems and Equipment - Voltage Ratings (60 Hertz)." American National Standards Institute, Inc.

<sup>2</sup> Duwadi, Kapil, Killian McKenna, Akshay Jain, Kajal Gaur, Adarsh Nagarajan, and David Palchak. 2021. "An Analysis Framework for Distribution Network DER Integration in India: Distributed Solar in Tamil Nadu." *Renewable Energy*, March. <https://www.nrel.gov/docs/fv21osti/78114.pdf>.

# System Average Risk Duration Indices (SARDI): An Overview Cont'd

SARDI metrics can be further split up and calculated for different types of violations on different types of assets. The following are used in this analysis.

- o **SARDI Voltage:** Percentage of time duration within the modeling timeframe for which the average customer is at risk of experiencing a voltage violation.
- o **SARDI Line:** Percentage of time duration within the modeling timeframe for which the average customer is at risk of experiencing a thermal violation on an upstream overhead wire or underground cable.
- o **SARDI Transformer:** Percentage of time duration within the modeling timeframe for which the average customer is at risk of experiencing a thermal violation on an upstream transformer.
- o **SARDI Aggregated:** Percentage of time duration within the modeling timeframe for which the average customer is at risk of experiencing any type of violation.

$$\text{SARDI}_{\text{voltage}} = \frac{\sum_{t=0}^T N_{VAC}^t \times \Delta T \times 100}{N_c \times T}$$
$$\text{SARDI}_{\text{line}} = \frac{\sum_{t=0}^T N_{LAC}^t \times \Delta T \times 100}{N_c \times T}$$
$$\text{SARDI}_{\text{transformer}} = \frac{\sum_{t=0}^T N_{TAC}^t \times \Delta T \times 100}{N_c \times T}$$
$$\text{SARDI}_{\text{aggregated}} = \frac{\sum_{t=0}^T N_{AC}^t \times \Delta T \times 100}{N_c \times T}$$

$N_{VAC}^t$  = number of unique customers affected by voltage violation  
 $N_{LAC}^t$  = number of unique customers affected by line overload  
 $N_{TAC}^t$  = number of unique customers affected by xfmr overload  
 $N_{AC}^t$  = number of unique customers affected by voltage, line, or transformer violation  
 $\Delta T$  = simulation timestep  
 $N_c$  = total number of customers



# Generalized Grid Impacts from Distributed Energy Resources

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- **Voltage Impacts:**
  - o While loads (energy consumption) pull system voltages *down* and can result in undervoltages (voltages *below* the minimum acceptable tolerance), distributed energy generation at the grid edge has the opposite effect, raising voltages most severely at their point of connection (often referred to as the point of common coupling or PCC). The extent of these effects are determined by a number of factors including the location on the grid, size of the DER, ratio of distributed generation to load at a given time, and system impedances. This effect is generally more pronounced during periods with relatively low load, when more solar generation is pushed back onto the grid rather than consumed onsite. It is not uncommon for utility engineers and power-system modelers to look at a worst-case scenario when studying DER grid impacts which is often when loads are at a minimum and distributed generation is at a maximum (also referred to as minimum daytime load or MDL).
- **Thermal Loading Impacts:**
  - o Adding distributed generation can reduce the loading of grid assets as they can produce energy at the location at which it is consumed rather than requiring the load to draw from the grid. However, at high adoption levels or when energy demand does not coincide with high solar production, the reverse power flow from distributed generation can *increase* loading on assets in the opposite direction.
  - o **System Losses:**
    - o Distributed generation has the potential to reduce system losses by providing energy generation at the same location at which it is consumed, reducing the power drawn from the grid. At especially high adoption levels, or on circuits where energy demand does not coincide with high solar production hours, the reverse power flow from distributed generation can *increase* losses as well.
- **DER Impacts not explored in this study:**
  - o System protection, grid reliability, system operations, switching procedures, or effects on the bulk power system stability and reliability.

# Assumptions in Distribution Modeling

- **Significant assumptions:**

- o The average load profiles used represent a "typical" residential and commercial customer, provided by DTE, and are applied to *all* loads in each customer class. In reality, every customer load profile varies, which would ultimately affect the coincident peak demand seen on segments of the feeder and individual grid assets. Unique customer loads profiles can only be captured through fine-time-resolution data from advanced metering infrastructure (AMI) or other recording meter.
- o Peak load allocation algorithms in [CYME](#) modeling software are used to find out the peak load for each customers based on substation SCADA and individual monthly energy consumption. In reality, *energy* consumption is not a perfect indicator of peak *power* demand.
- o For secondary modeling we mapped spot loads from [CYME](#) to buildings available from Open Street data and [Microsoft Parcel Data](#). There may be a mismatch in the number, location, or size of buildings, resulting in potentially inaccurate load-flow results or customer counts.
- o The analysis tools used in this study (EVOLVE, EMERGE, and REopt) also include assumptions regarding typical customer behaviors, geographic patterns of DERs adoption, and technical characteristics of DERs. Given the inherent uncertainties in predicting these items and the lack of granular, locationally accurate datasets to inform this study, these assumptions may differ from the actual current and future conditions within Highland Park.
- o As mentioned on the previous slide, there are multiple types of DER impacts not explored in this study.

- **Interpretation of study results:**

- o The results of this study can reasonably illustrate high-level trends under the scenarios we generate, but in general cannot pinpoint the more granular impacts on individual lines, transformers, or single customers.
- o Scenarios can forecast changes to customer loads profiles based on a set of initial conditions and assumptions but cannot predict the future with a high degree of certainty.
- o Results can also reasonably illustrate the types of violations on a system (i.e., namely impacts on the secondary (low-voltage) networks rather than primary networks, or voltage impacts instead of thermal overloads). These findings can provide valuable insights for utility planning, design, and operations.

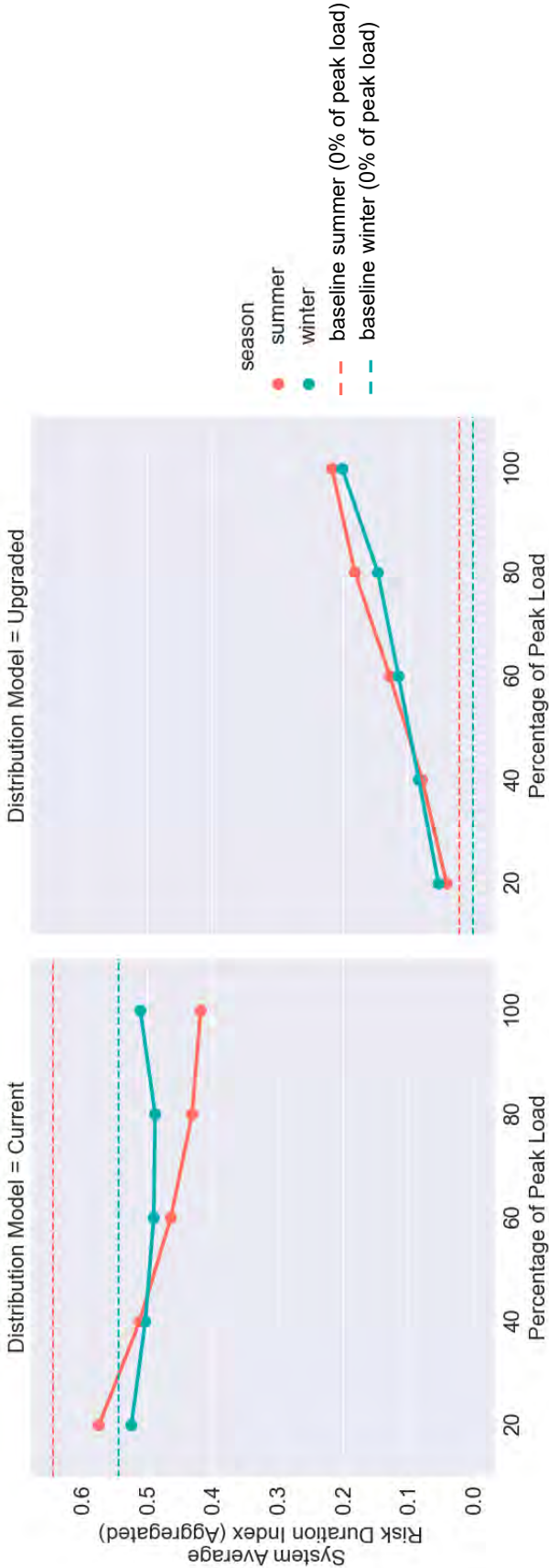
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# Scenario Analysis Results

# Rooftop Solar Only (Base Electrification): Grid Impacts

## Rooftop Solar (Base Electrification): SARDI Aggregated

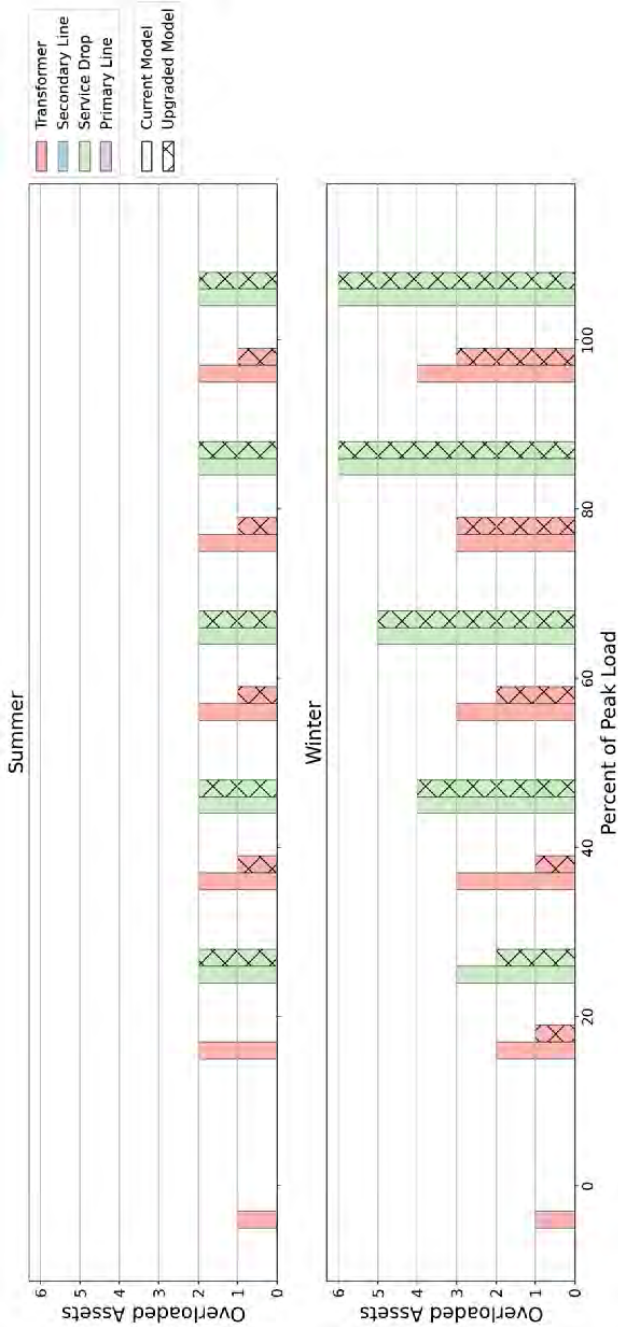
The SARDI aggregated metric is relatively small for our solar-only scenario under the current base electrification. With no solar added to our Current Model, we see a baseline risk of roughly 0.65% and 0.55% in summer and winter, respectively. As we add solar to our Current Model, system-level risk tends to decrease, rising slightly at high adoption rates in the winter. On the Upgraded Model, we start from a lower baseline of near 0% for both summer and winter and see an increase in risk with increasing solar adoption, though overall, a lower risk across all adoption levels compared to our Current Model. Note this risk is mainly due to thermal overloading of lines and/or transformers. We did not observe voltage violations in these scenarios.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average SARDI ranking across 25 simulation samples.

## Rooftop Solar (Base Electrification): Number of Overloaded Assets

The relatively low SARDI score is further reflected in the small number of overloaded assets shown below. Overloads are exclusive to a handful of transformers and service drops and tend to improve or stay the same when upgrading the system. It is important to recognize that despite upgrading our feeder from 4.8 kV to 13.2 kV, the voltages of our secondary (low-voltage) lines do not change (120/240V in both models) and so the improvements here are relatively small and namely reflect changes in transformer sizes in select cases (i.e., when the existing transformer had a capacity of less than 50 kVA). There are no overloaded primary lines, even at 100% solar adoption. There are generally more overloaded assets in the wintertime (bottom) due to lower energy demand and higher back feed of solar generation onto the distribution network, illustrated particularly at high levels of solar adoption.

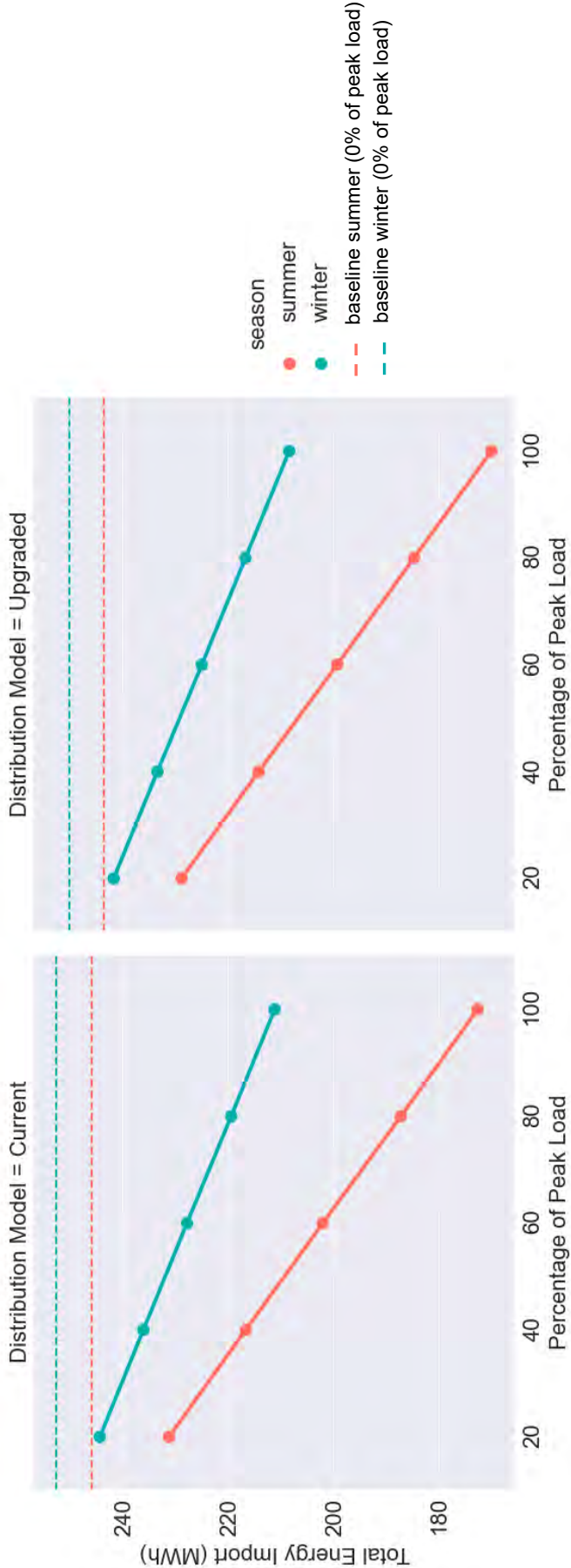


Percentage of Peak Load is defined as % of peak before introducing distributed energy resources. The bar plots shown take the max number of overloaded assets across 25 simulation samples.



## Rooftop Solar (Base Electrification): Total Energy Import

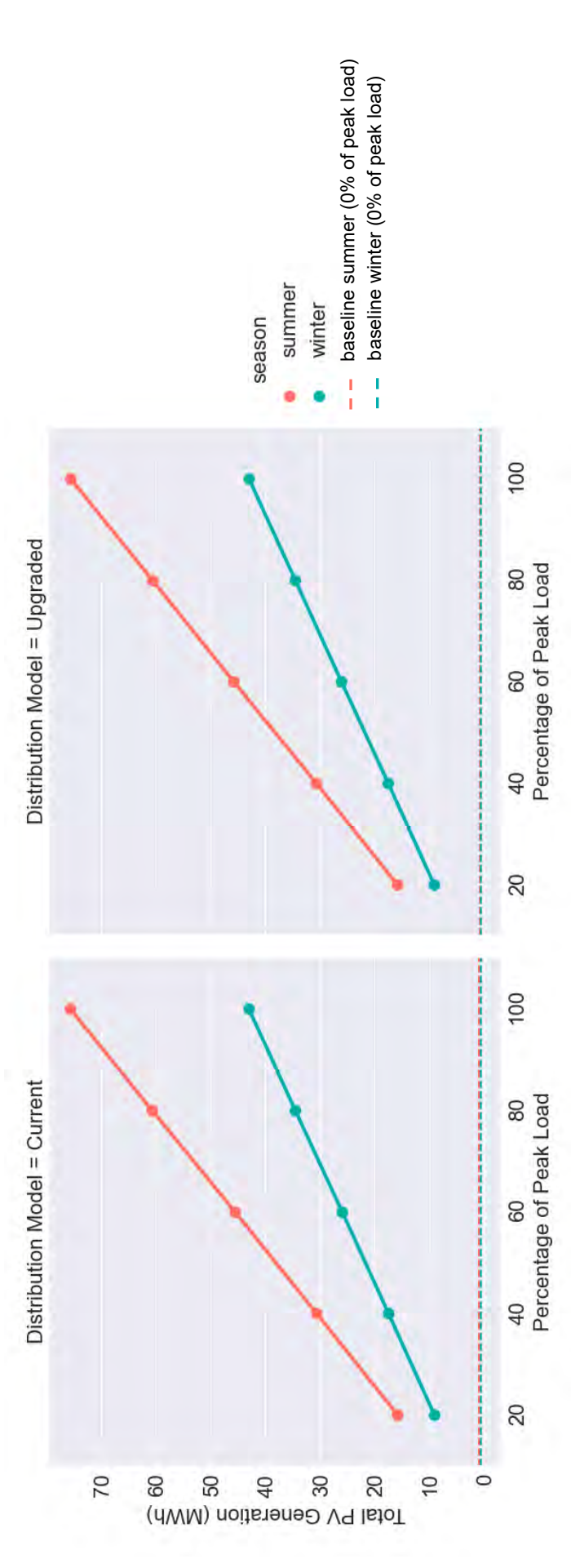
As one would expect, energy import (energy produced by bulk system generation and transported across high-voltage transmission networks) reduces with increasing distributed solar adoption. We see a greater reduction during the summer due to increased irradiance from the sun and more daylight hours. The further reduction in imports (albeit very slight) we see on our Upgraded Model is due to reduced line and transformer losses in the upgraded system, illustrated in more detail on slide 27.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average SARDI ranking across 25 simulation samples.

## Rooftop Solar (Base Electrification): Total PV Generation

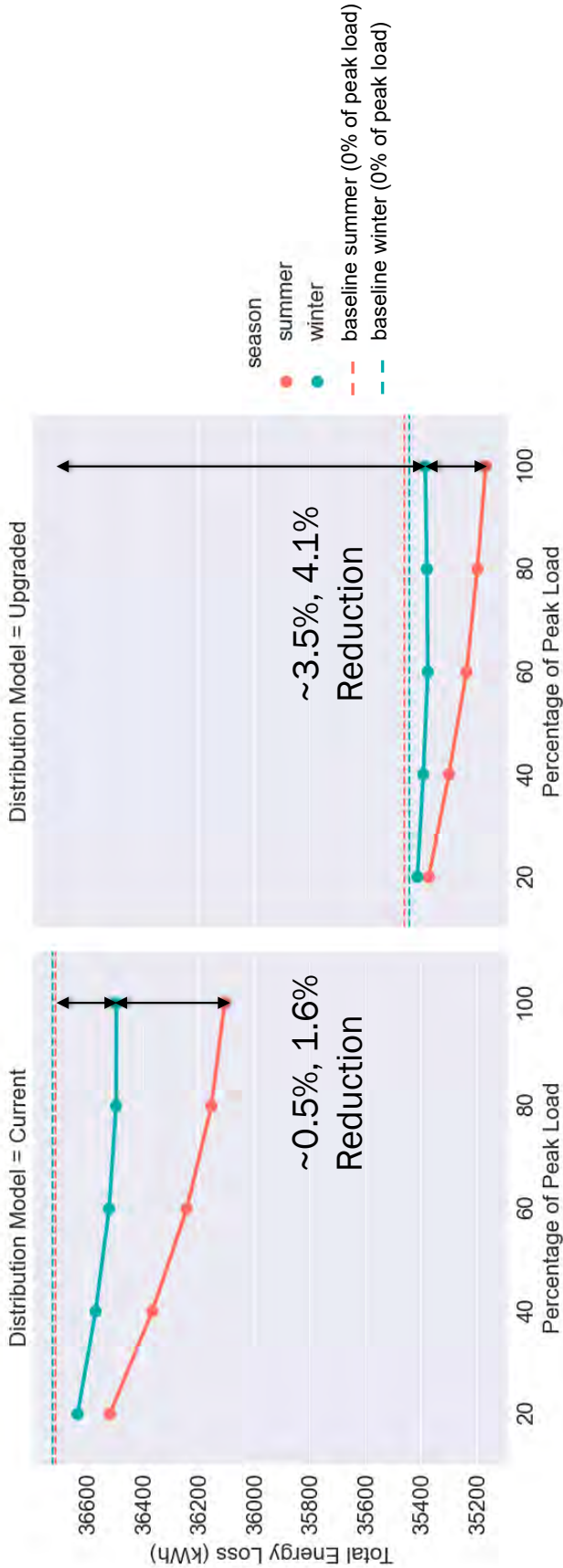
Conversely to energy imports, distributed solar generation increases with increasing solar adoption. We see higher solar generation in the summer due to higher solar irradiance and longer days. Here there is no difference in generation between our Current and Upgraded Models because the peak load (and thus the assigned solar system sizes) is the same in both models for the current electrification scenario.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average SARDI ranking across 25 simulation samples.

## Rooftop Solar (Base Electrification): System Losses

System losses tend to reduce with increasing solar adoption as confirmed by the plots below. In our Current Model, we see a peak loss reduction of about 0.5% and 1.6% at 100% solar adoption in the winter and summer, respectively, compared to the baseline. The Upgraded Model sees a *further* reduction in losses for a peak of 3.5% and 4.1% reductions for winter and summer, respectively, when compared to baseline in our Current Model. The additional reduction is largely resultant from lower current flow due to operating at a higher voltage class, as well as larger assets with lower impedances per DTE's upgrade design guidance (see slide 14). For reference, the Current Model's system losses with no solar adoption is ~36.7 MWh (winter) or ~14.7% of energy imported (winter). The Upgraded Model's system losses are ~35.4 MWh (winter) or ~14.1% of energy imported (winter).



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average SARDI ranking across 25 simulation samples.

## Key Takeaways

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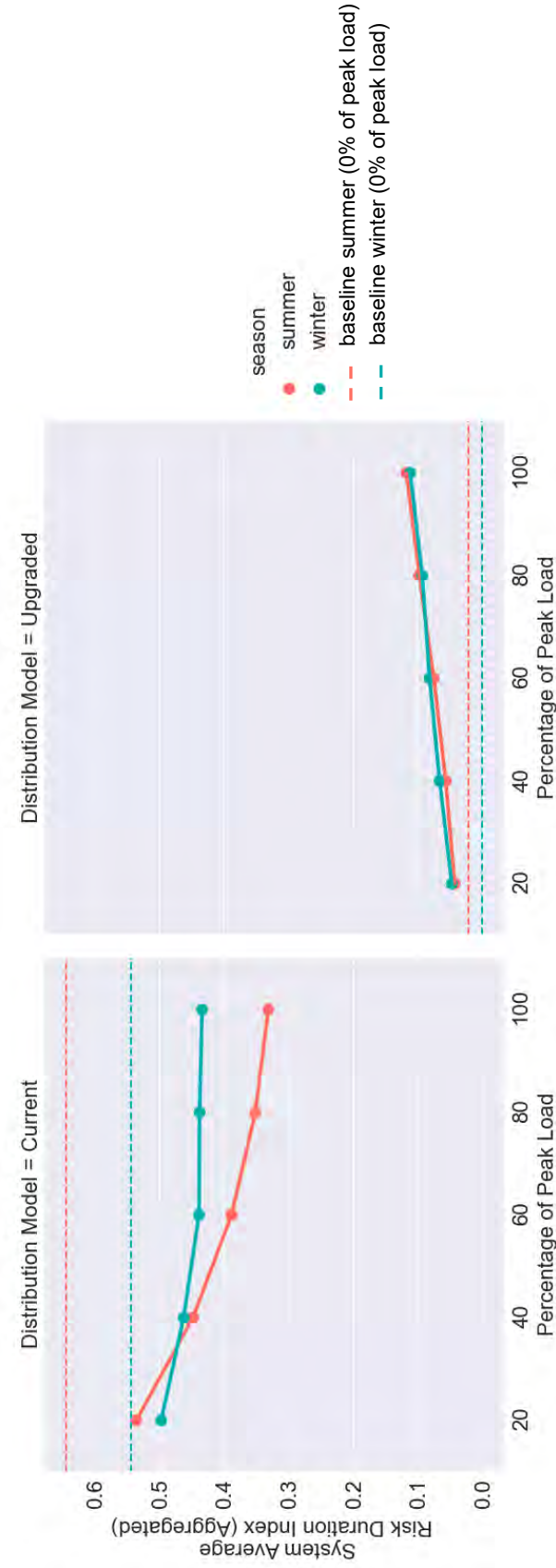
- While only minimal system risks are seen in this solar-only scenario, the SARDI aggregated metric shows that adding rooftop solar generally reduces the risk associated with asset overloading in the current model.
- Adding solar in the upgraded model increases overall system risk, though values are still lower than what the *current* grid is experiencing.
- All overloaded assets, with and without solar, are limited to the low-voltage secondary distribution network (from distribution transformer to customer meter), a trend which continues throughout this analysis illustrated on the following slides. No thermal impacts are seen on the medium-voltage primary network.
- Assuming customers would choose this cost-optimal solar size (as recommended by REopt), total energy import would be reduced by about 24% in summer and 14% in winter with a 100% solar adoption level.
- The adoption of distributed solar reduces energy losses by up to 1.6% on the current system and up to 4.1% in the upgraded feeder, when compared with the current model baseline.

# Rooftop Solar and Energy Storage (Base Electrification): Grid Impacts



# Rooftop Solar and Energy Storage (Base Electrification): SARDI Aggregated

In our solar + storage scenario, we see almost identical trends to our solar-only model shown previously. We see small overall risk levels of about 0.65% in our baseline, decreasing with higher solar adoption levels and overall lower risk levels in our Upgraded Model. The slight improvements from added energy storage are illustrated on a later slide in more detail. Note, this risk is mainly due to thermal overloading of line and/or transformers. We did not observe voltage violations in these scenarios.

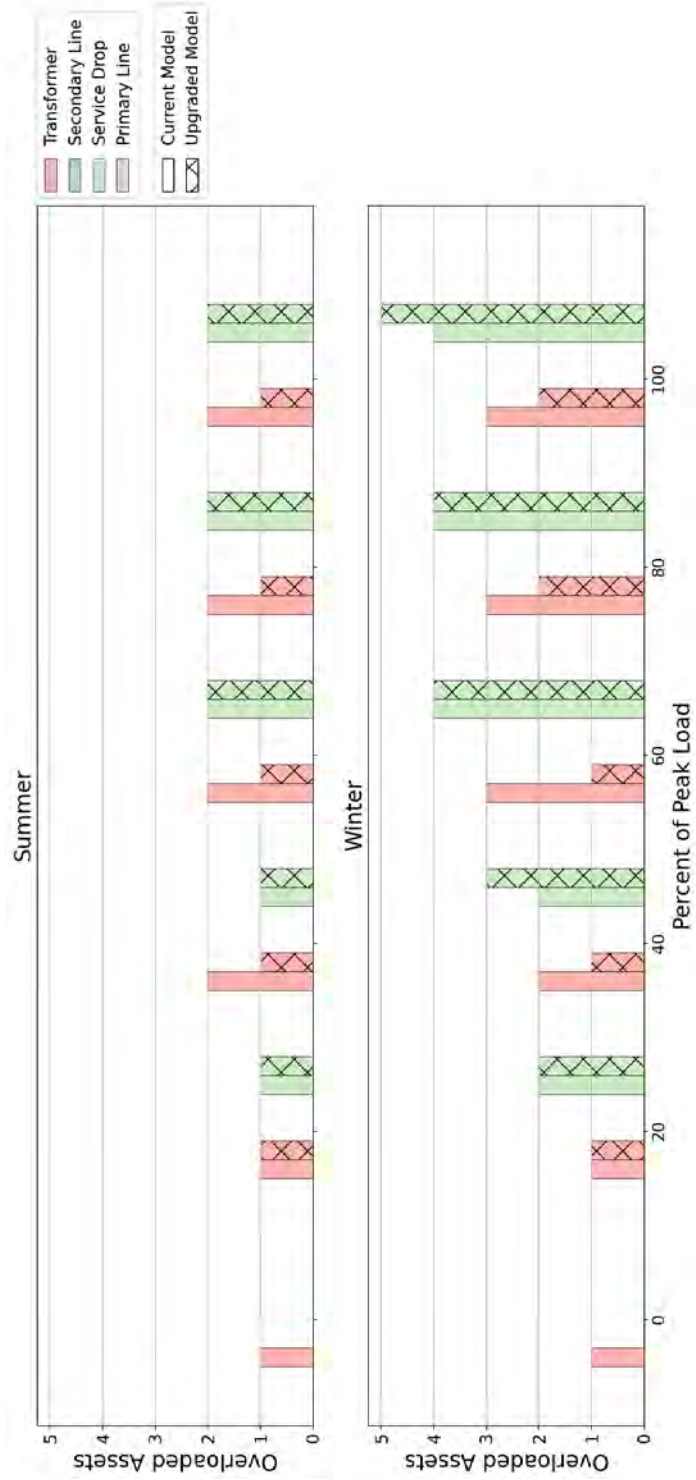


Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.



## Rooftop Solar and Energy Storage (Base Electrification): Number of Overloaded Assets

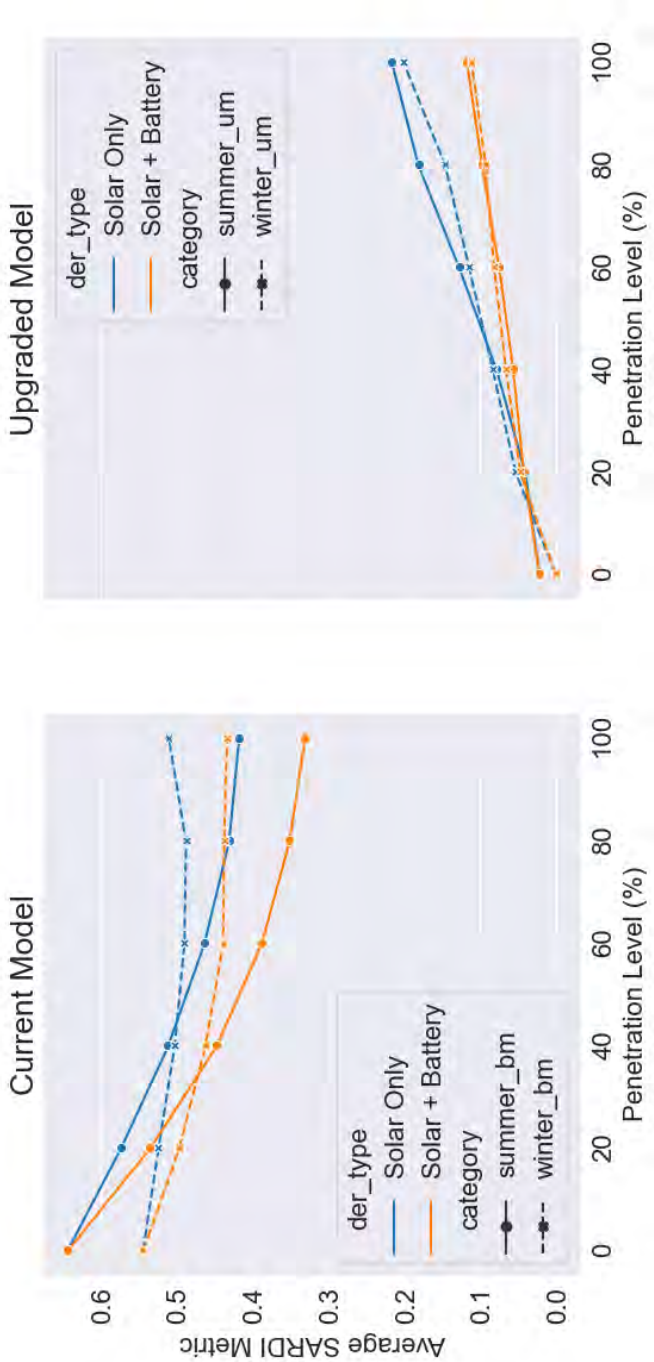
We see an almost identical number of overloaded assets compared with our solar-only model with the addition of energy storage. At high levels of adoption, we see a slight reduction in overloaded assets, illustrated in more detail on the following slide.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The bar plots shown take the max number of overloaded assets across 25 simulation samples.

# Solar vs. Solar and Energy Storage (Base Electrification): Comparison

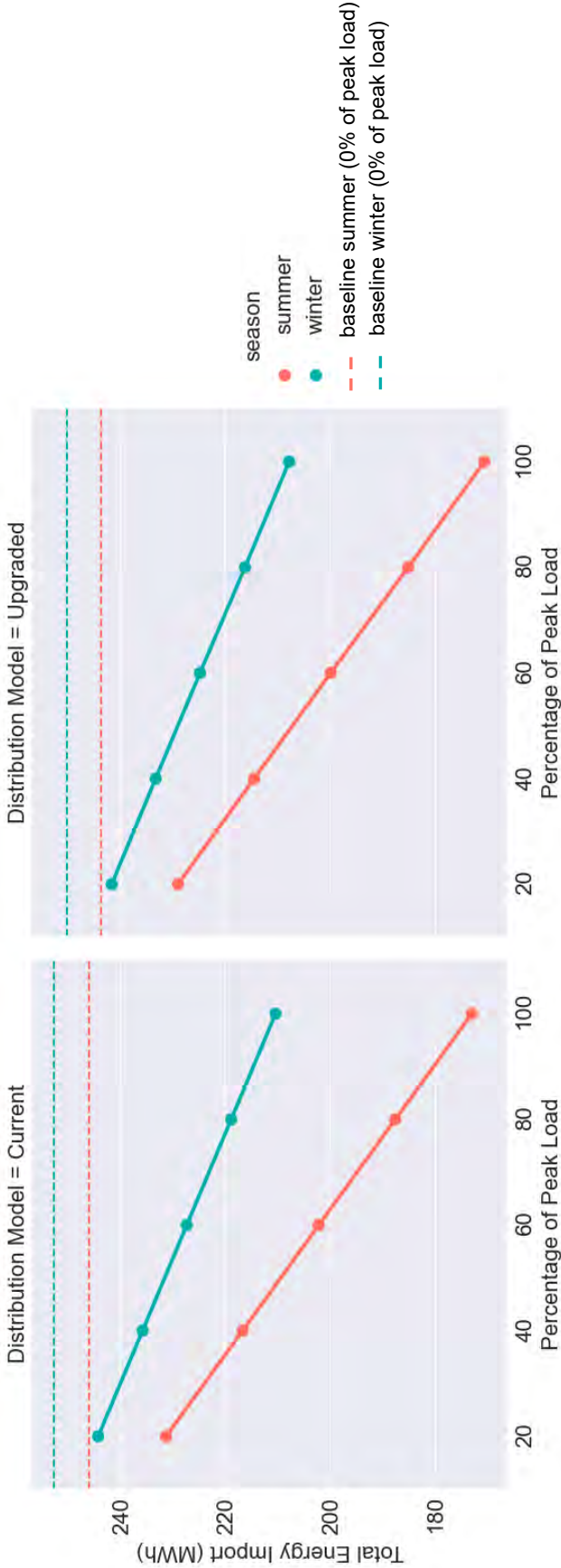
Incorporating behind-the-meter energy storage in our models further reduces system risk in both the Current and Upgraded models. The added storage enables homeowners to consume more of the energy their rooftop solar generates by storing energy during periods of low load, rather than exporting energy back onto the distribution system. This ultimately results in fewer solar-caused violations and the associated risks.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.

# Rooftop Solar and Energy Storage (Base Electrification): Total Energy Import

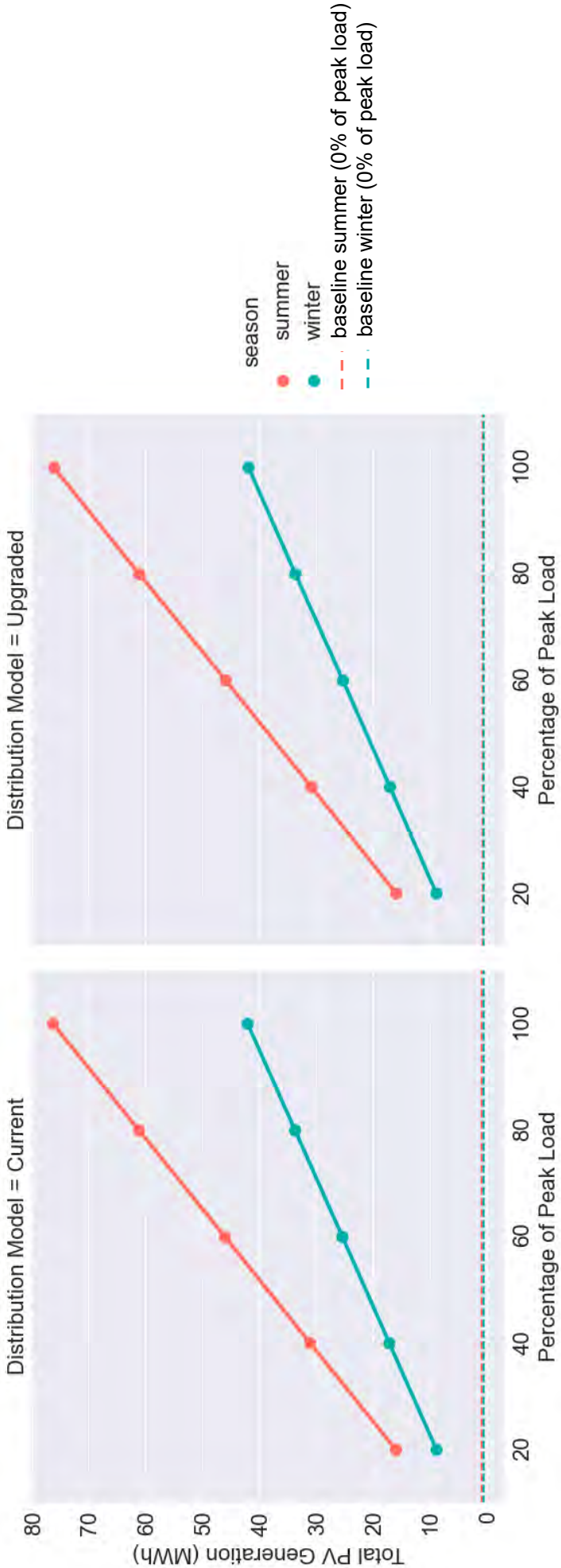
We see almost identical trends to our solar-only model, illustrating that behind-the-meter energy storage, as we have implemented it, does not have major impacts on overall energy consumption from the bulk power system. Batteries may charge from onsite solar or from the grid, however, given that this stored energy is discharged at a later time, we see no net changes in overall energy consumption, compared with the solar-only scenario.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.

# Rooftop Solar and Energy Storage (Base Electrification): Total PV Generation

Our modeling of PV systems does not change between our solar-only vs. solar + storage models. As such, we see no differences in generation from PV compared across the two scenarios.

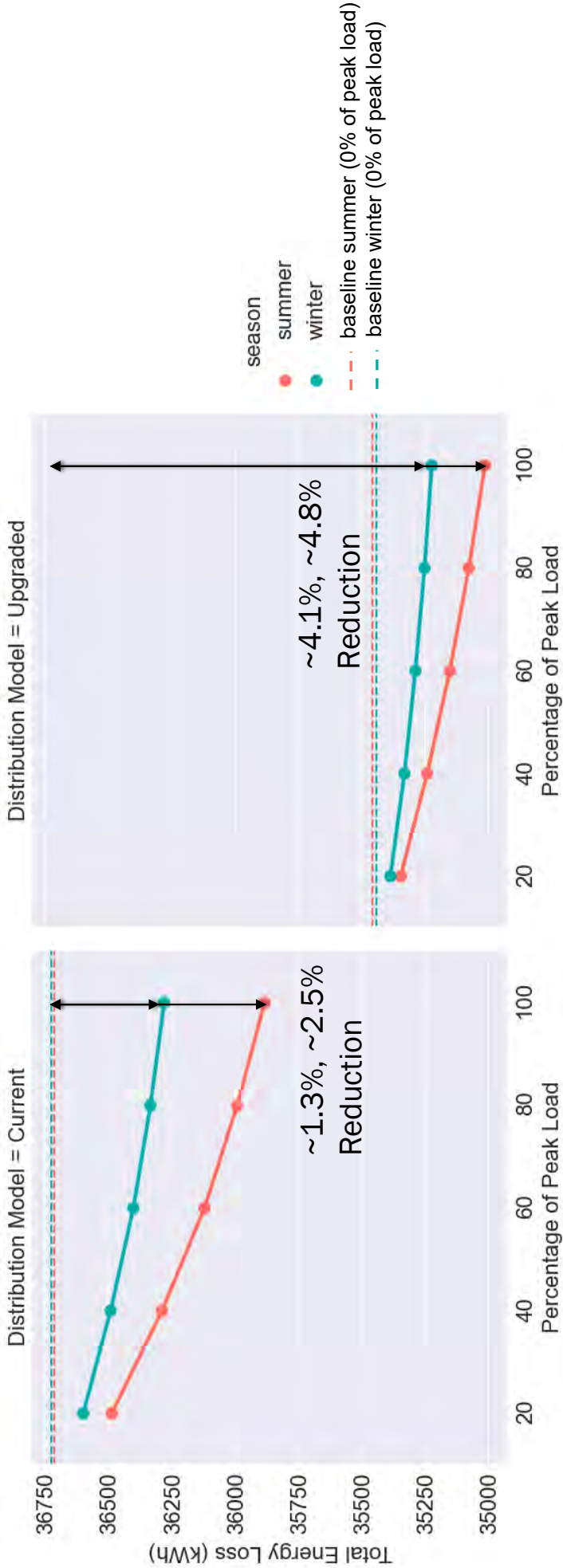


Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.



# Rooftop Solar and Energy Storage (Base Electrification): System Losses

Adding behind-the-meter energy storage results in slight improvements in system losses when compared to our solar model, due largely to a reduction in solar exports and increased onsite consumption. The additional loss reduction is, albeit, slight, with a peak reduction of 2.5% vs. 1.3% and 4.8% vs 4.1% in our Current and Upgraded models, respectively.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.

## Key Takeaways

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- Again, while only minimal system risks are seen in this scenario, the SARDI aggregated metric shows that adding energy storage alongside rooftop solar can further reduce risk.
- Overloaded assets are exclusive to the low-voltage network and service transformers. No impacts to the medium-voltage primary network are seen.
- Adding behind-the-meter energy storage results in slight improvements in system losses when compared to our solar scenario, due largely to a reduction in solar exports and increased onsite consumption.
- Overall, the current 4.8 kV system does not appear to be a severe limitation to the adoption of distributed cost-optimal rooftop solar plus behind-the-meter storage systems for this region of Highland Park. Larger rooftop solar systems or utility-scale installations may be more limited by the legacy distribution voltage class.



# Rooftop Solar Only (Future Electrification): Grid Impacts

# Rooftop Solar (Future Electrification): Notes

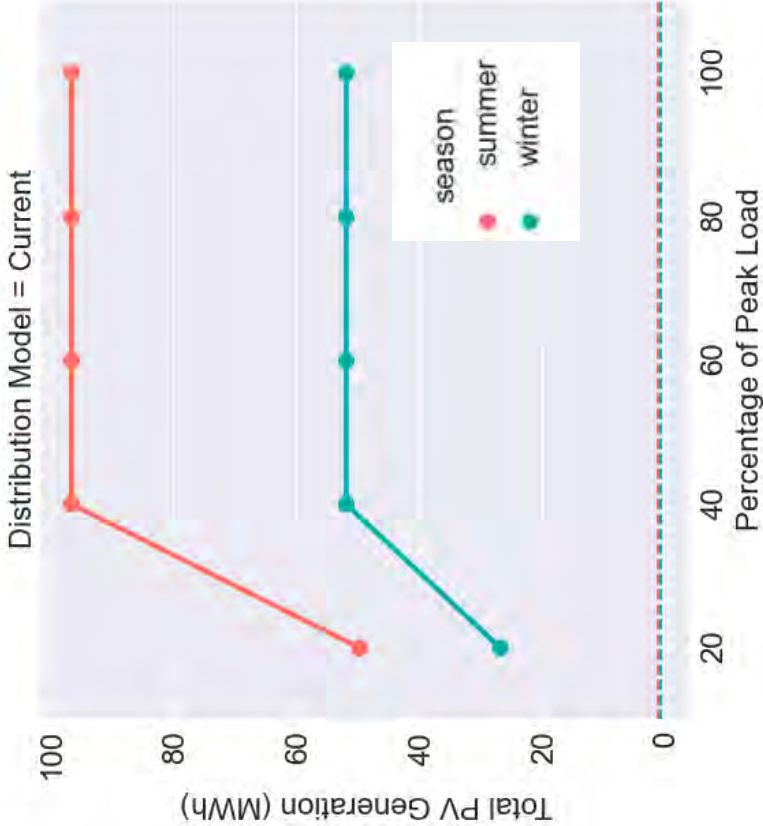
A nuance of our scenario development approach, seen in our Rooftop Solar (Future Electrification) scenario is shown in the plot of total PV generation.

**With the added loads of building electrification, we cannot meet more than 40% of the system peak load with cost-optimal rooftop solar installed at every residence.** This results in a leveling off of solar generation and the resulting risk metrics beyond 40% adoption. This result is due, in part, to the relatively small individual solar PV systems installed at each house, prescribed as the cost-optimal size from the accompanying REopt analysis.

Additionally, the overall much higher loads from electrified heating produces a circuit where to meet 40% of the system peak load in installed solar capacity using cost-optimal system sizes, 100% of customers on this circuit need to have solar installed. Beyond this point, there are physically no more rooftops on which to install more solar, and as such, solar generation and the risk metrics do not change beyond this point. Details on why the smaller PV systems are still the cost-optimal option are presented in the accompanying presentation describing the REopt analysis.<sup>1</sup>

One should also note that nearly all the increased energy consumption due to electrification occurs in the wintertime. As such, summer metrics are relatively unchanged from previously shown scenarios. This trend will largely hold true for the remaining future electrification scenarios.

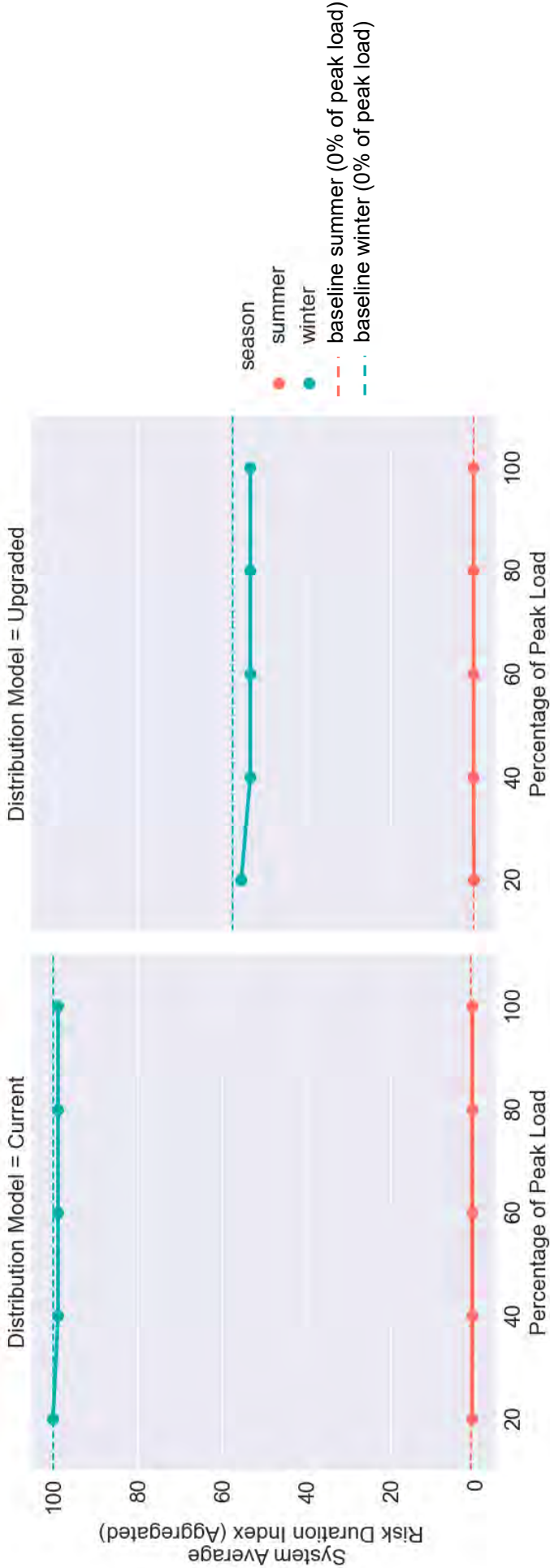
<sup>1</sup> Oddleifson, Tucker, Kapil Duwadi, Erik Pohl, Patrick Gibbs, Shibani Ghosh, Chrissy Scarpitti, and Liz Weber. 2024. "Feasibility Analysis of Behind-the-Meter Distributed Energy Resources in Highland Park, MI." February. <https://www.nrel.gov/docs/fy24osti/87988.pdf>.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.

## Rooftop Solar (Future Electrification): SARDI Aggregated

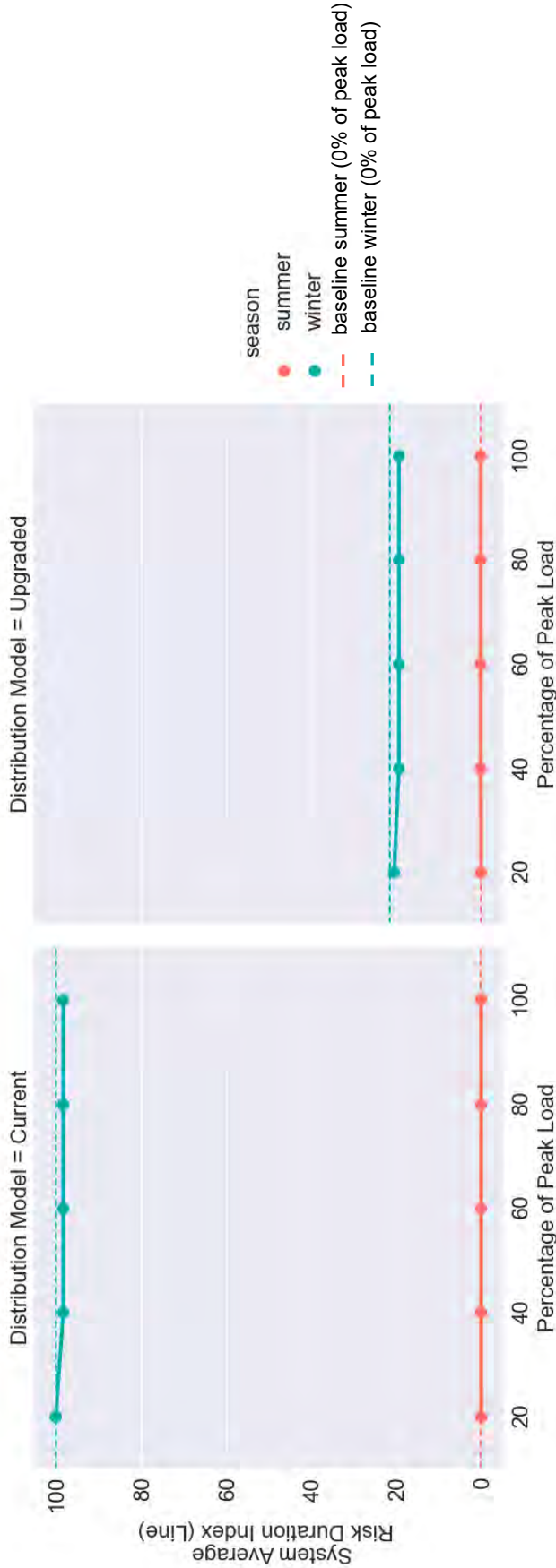
The added loads in our Future Electrification scenarios result in far higher risk levels during the winter months, when electric heating loads are present. A SARDI Aggregated score of 100 indicates that 100% of the customers are located downstream of an at-risk asset for 100% of the modeling timeframe. The significant drop in SARDI Aggregated score in the Upgraded model is driven primarily by a reduction in line overloads. The following slides provide a more detailed breakdown of this score.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The bar plots shown take the max number of overloaded assets across 25 simulation samples.

## Rooftop Solar (Future Electrification): SARDI Line

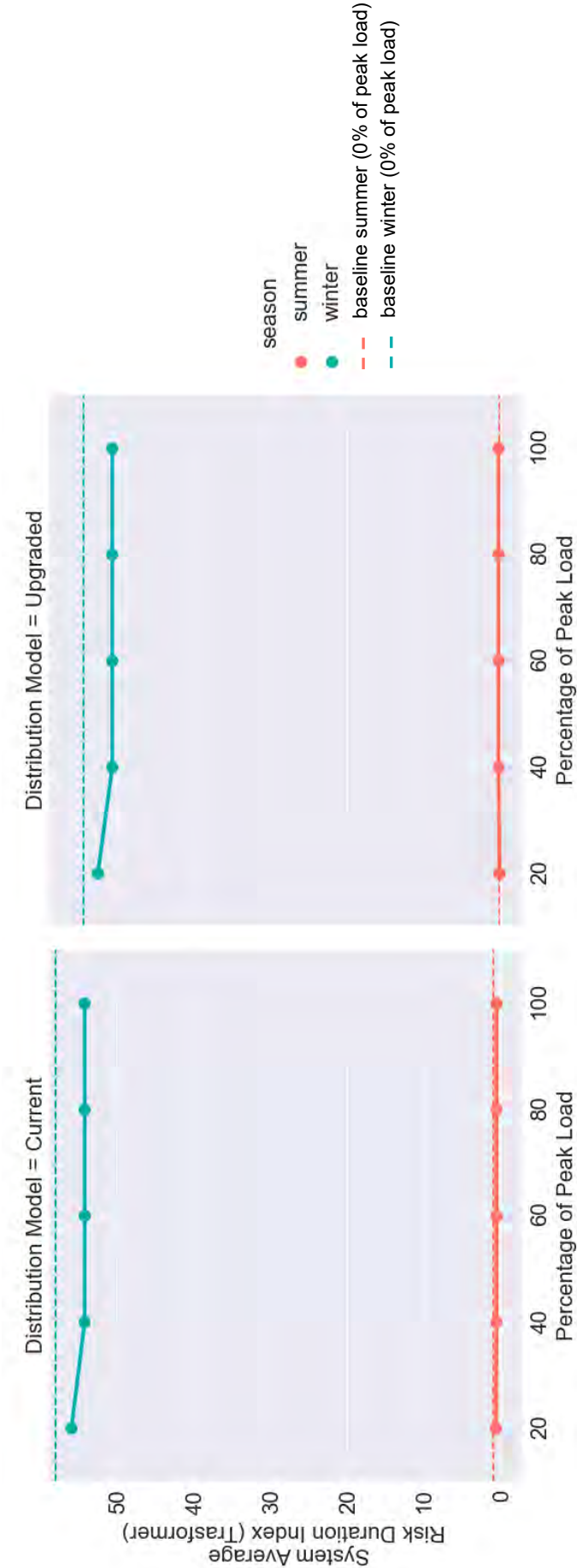
The high SARDI Aggregated score is driven in a large part by overloaded cables and wires, including central assets located in close proximity to the substation. On our Current Model, we see practically no changes to our summer risk levels (once again, almost zero). During the winter, we see an initial SARDI Line of 100%, followed by a slight decrease as solar alleviates some of these overloads until reaching saturation around 40% peak load. Once upgraded to a higher voltage class, we see a substantial drop in SARDI Line, with most remaining violations being located on the low-voltage networks. The remaining risks are indicative of potentially inadequate design standards if planning for a high-electrification future.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.

# Rooftop Solar (Future Electrification): SARDI Transformer

While our Upgraded Model includes larger transformers for those that were previously less than 50 kVA (replaced with a 50 kVA), the persistent high SARDI Transformer score in our Upgraded Model indicates that this rule of thumb may not be sufficient for high-electrification futures. The result suggests that further upgrades (i.e., swapping 50 kVA to 100 kVA transformers or splitting up customer counts onto *additional* transformers) may be needed to accommodate larger household loads.

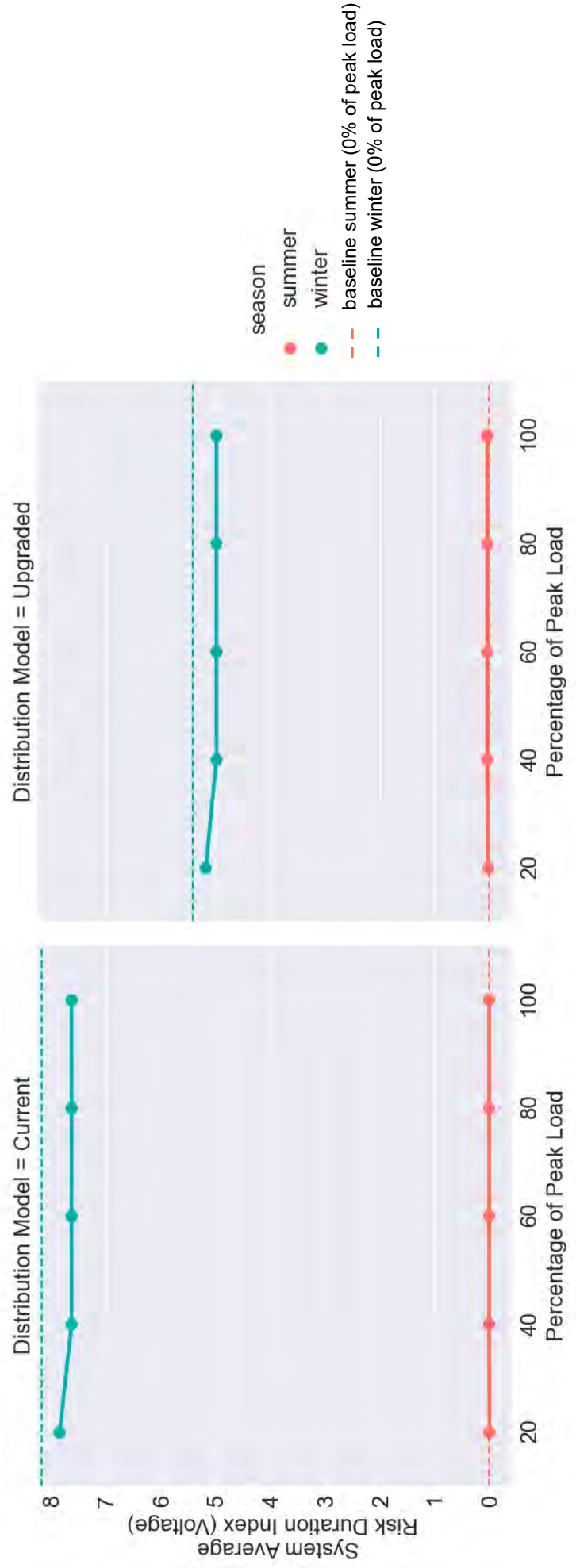


Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.



# Rooftop Solar (Future Electrification): SARDI Voltage

Our SARDI Voltage score in this scenario is relatively low, indicating that line ampacities and transformer kVA ratings are the main bottleneck for high-electrification futures. That said, the findings below illustrating persistent voltage violations after upgrading can still inform future design standards, possibly prescribing larger secondaries, added voltage regulation, or additional transformers to limit overall secondary lengths and resulting voltage drop.

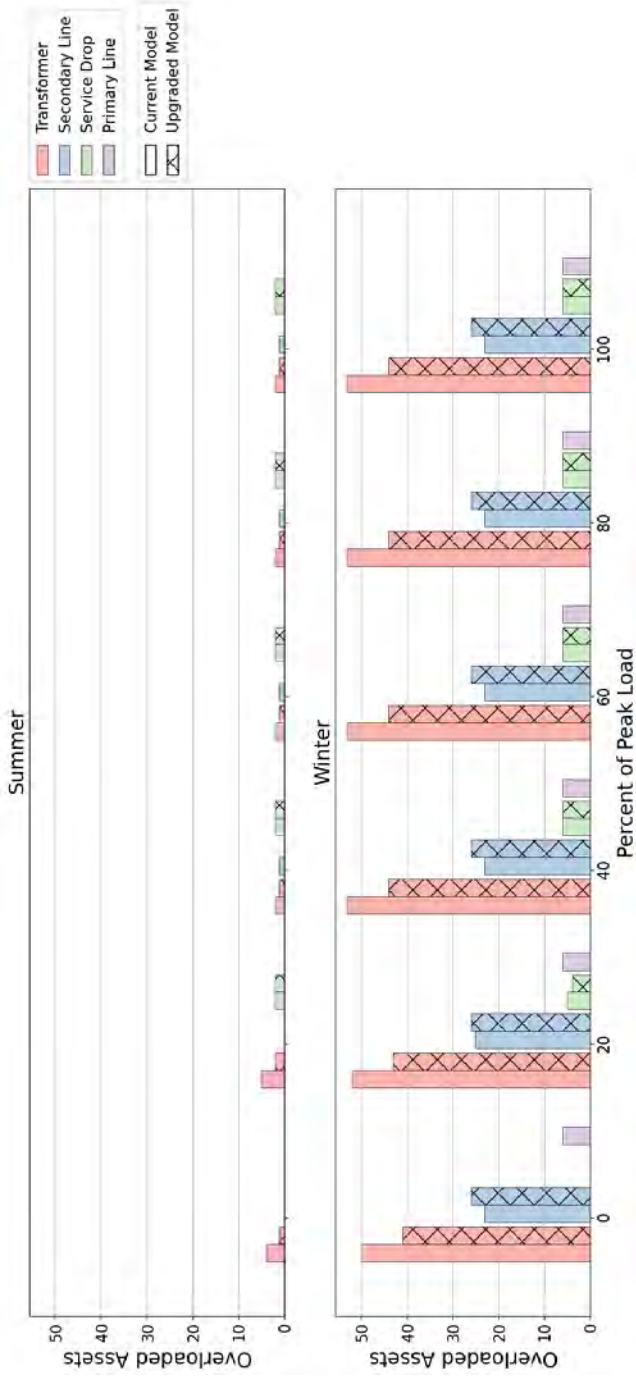


Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.



## Rooftop Solar (Future Electrification): Number of Overloaded Assets

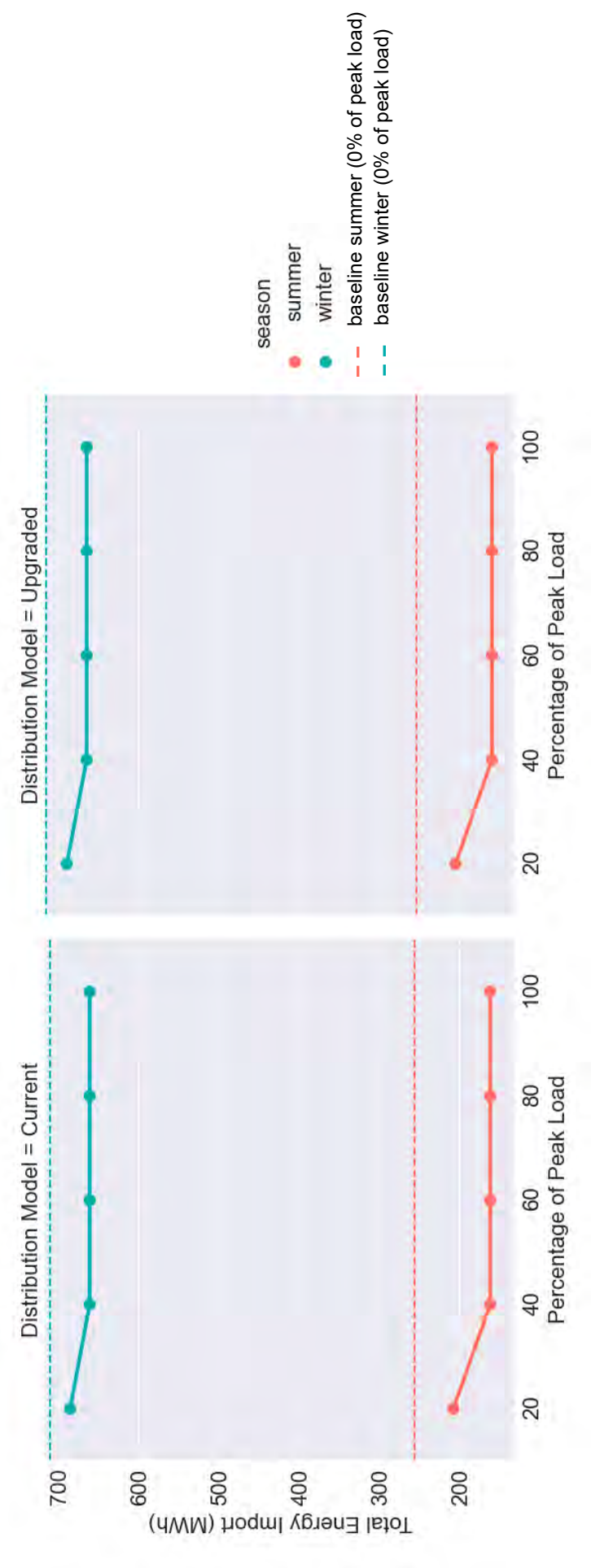
In our Future Electrification models, we see a much larger number of overloaded service transformers and secondary lines, almost exclusively in the wintertime. As previously noted, there are primary lines near the feeder head in our Current Model which are overloaded resulting in a SARDI Line of 100. While these primary line violations are remedied in our upgraded model, the majority of the overloaded service transformers, secondary lines and service drops remain overloaded in our upgraded model, again illustrating the need for more robust design standards if planning for a high-electrification future.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The bar plots shown take the max number of overloaded assets across 25 simulation samples.

# Rooftop Solar (Future Electrification): Total Energy Imports

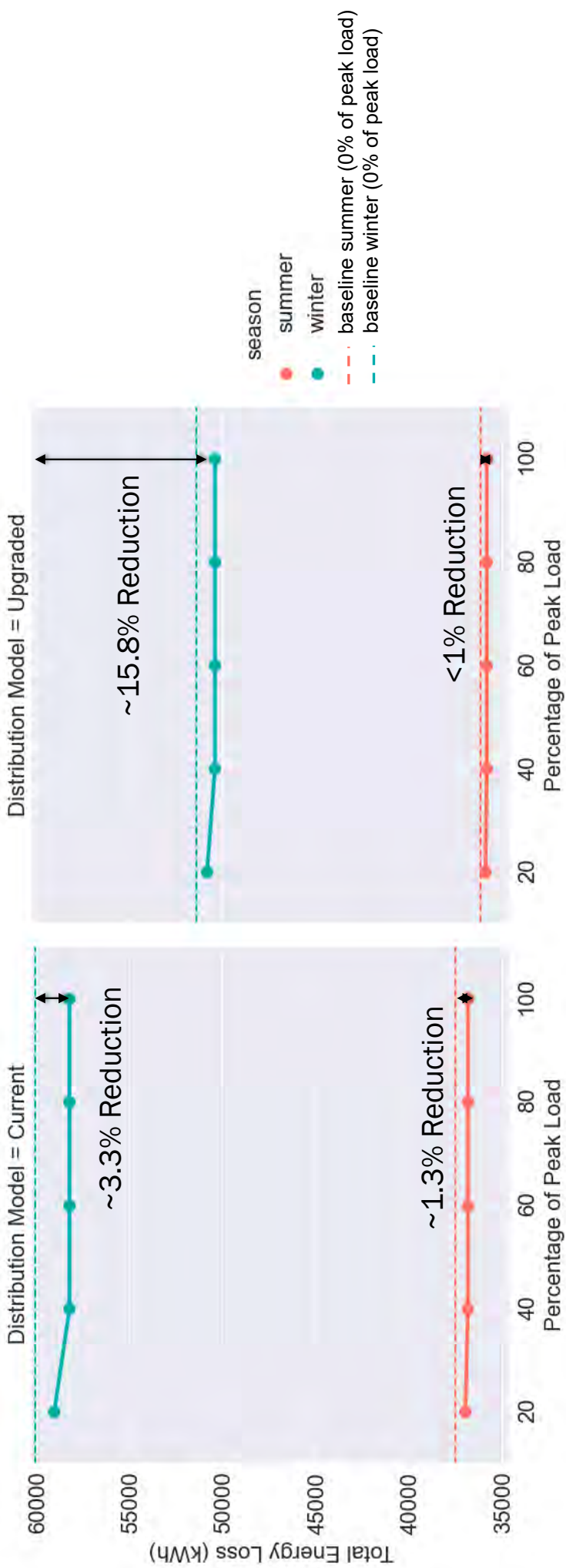
We see a dramatic increase in energy import (nearly 3X) in the wintertime due mainly to electric heating loads, and practically no increase in summertime consumption.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.

## Rooftop Solar (Future Electrification): System Losses

The significantly higher losses are a result of much higher loads from building electrification and wintertime heating loads. We see a large improvement in system losses when upgrading the circuit to a higher voltage class.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.

## Key Takeaways

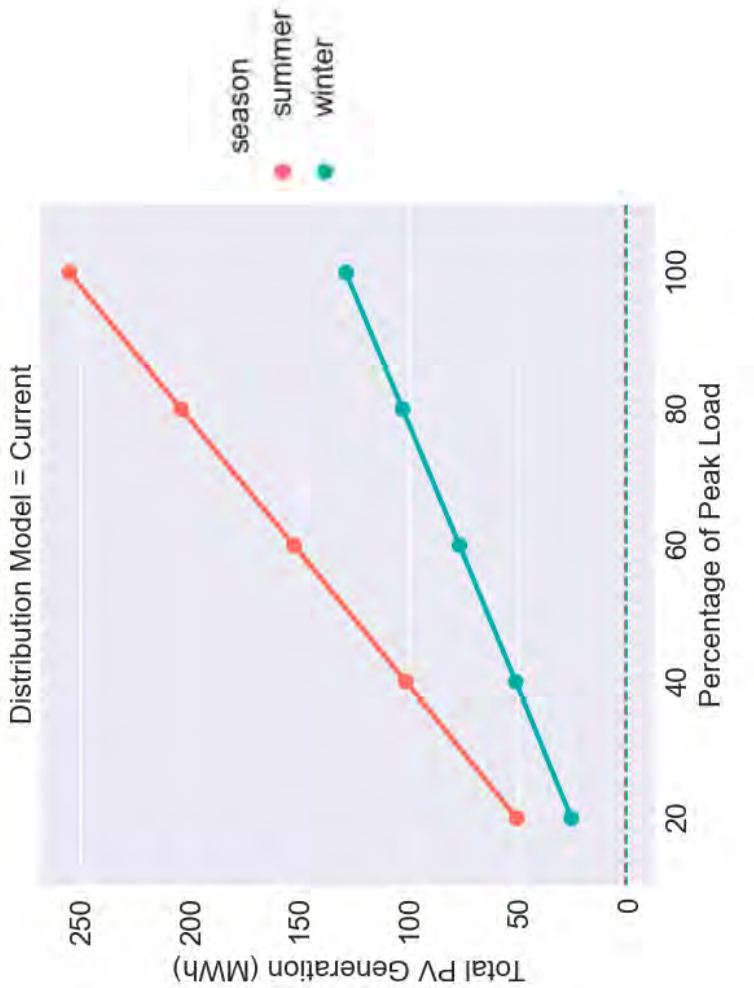
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- Significant load increases in our Future Electrification scenarios drastically increase the baseline system risk. This effect takes place almost exclusively in the wintertime, with little change in the summertime, due to the addition of electric heating loads, in place of gas furnaces.
- With no solar, we see a SARDI aggregated metric of 100, indicating that all customers are served by an at-risk asset for the duration of the modeling timeframe.
- The cost-optimal solar sizing algorithm used in REopt results in relatively small solar installations on each house when compared with the large increase in winter loading. This creates a saturation effect, around 40% adoption, at which point every house has solar installed. As a result, increasing solar adoption beyond this point is not possible, and risk metrics remain constant beyond this point.
- Upgrading the system produces large improvements in risks and system losses, however significant system risks remain on the Upgraded Model, namely in the form of overloaded secondary lines and overloaded transformers.
- Remaining high risk metrics in our upgraded model indicate the need for revised utility design standards, particularly for secondary systems. Revisions may include larger standard secondary conductors, fewer customers per transformer, or adding additional transformers to limit secondary lengths.

# Rooftop Solar and Energy Storage (Future Electrification): Grid Impacts

# Rooftop Solar and Energy Storage (Future Electrification): Notes

A notable difference resulting from the addition of energy storage, is that it increases the cost-optimal solar size recommended by REopt. As a result, we no longer see the saturation effect causing solar generation to level out, as we did in the previous solar-only scenario. This means that we can effectively meet even 100% of the system peak load with installed solar capacity, thanks to the increased self-consumption enabled by energy storage and larger individual solar installations. This phenomenon and solar sizing strategies are explained in more detail in the accompanying REopt analysis.

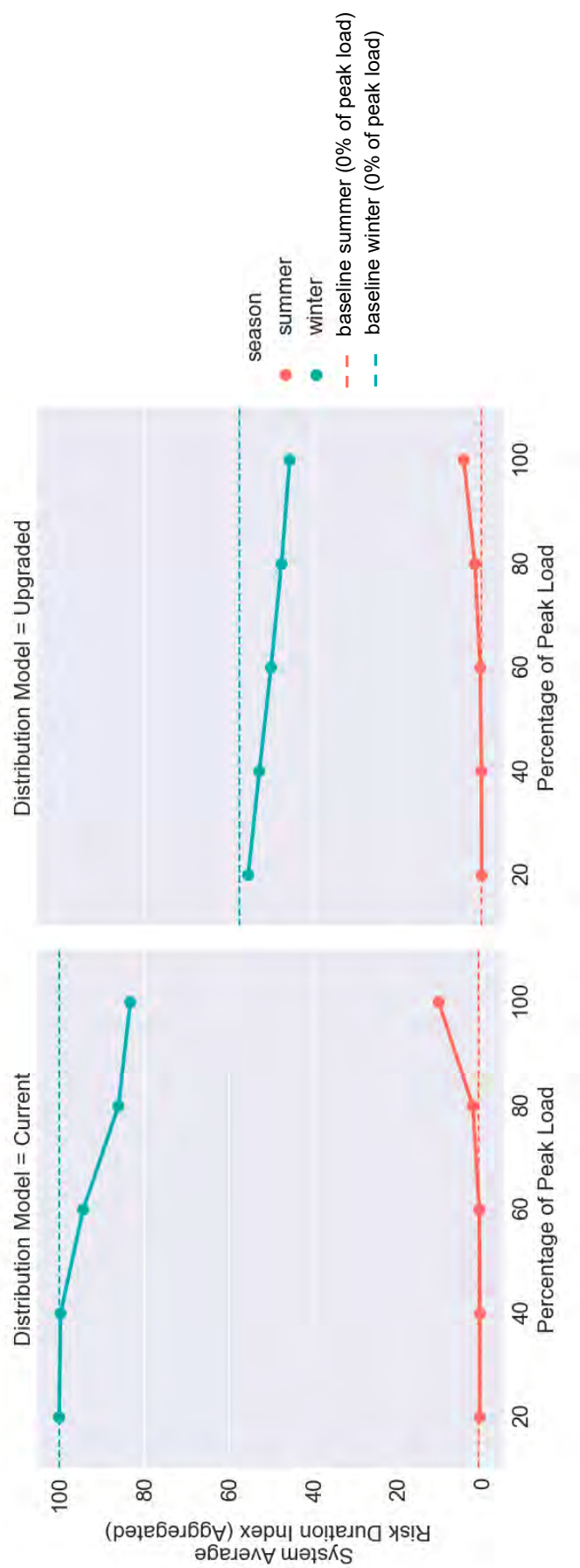


Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.



# Rooftop Solar and Energy Storage (Future Electrification): SARDI Aggregated

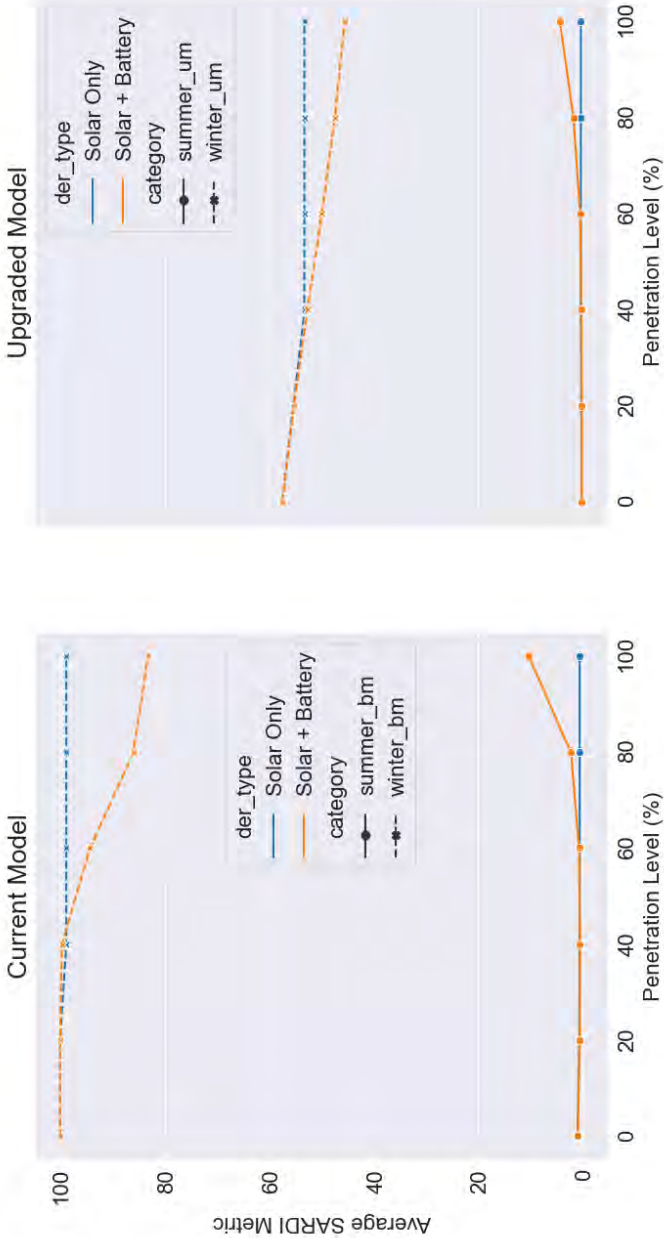
In contrast to our solar-only scenario, we see a consistent decrease in our wintertime risk with increasing solar adoption in both models. The opposite is true in the summertime. PV systems which are sized to accommodate the larger winter loads and energy storage will export more to the grid during the summertime given the higher irradiance and lower loads in the absence of electric heating. As such, at high levels of adoption, we see an uptick in risk. Our Upgraded Model overall shows a lower risk level, but similar to the solar-only scenario, there are still non-zero risks.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.

# Rooftop Solar and Energy Storage (Future Electrification): Comparison

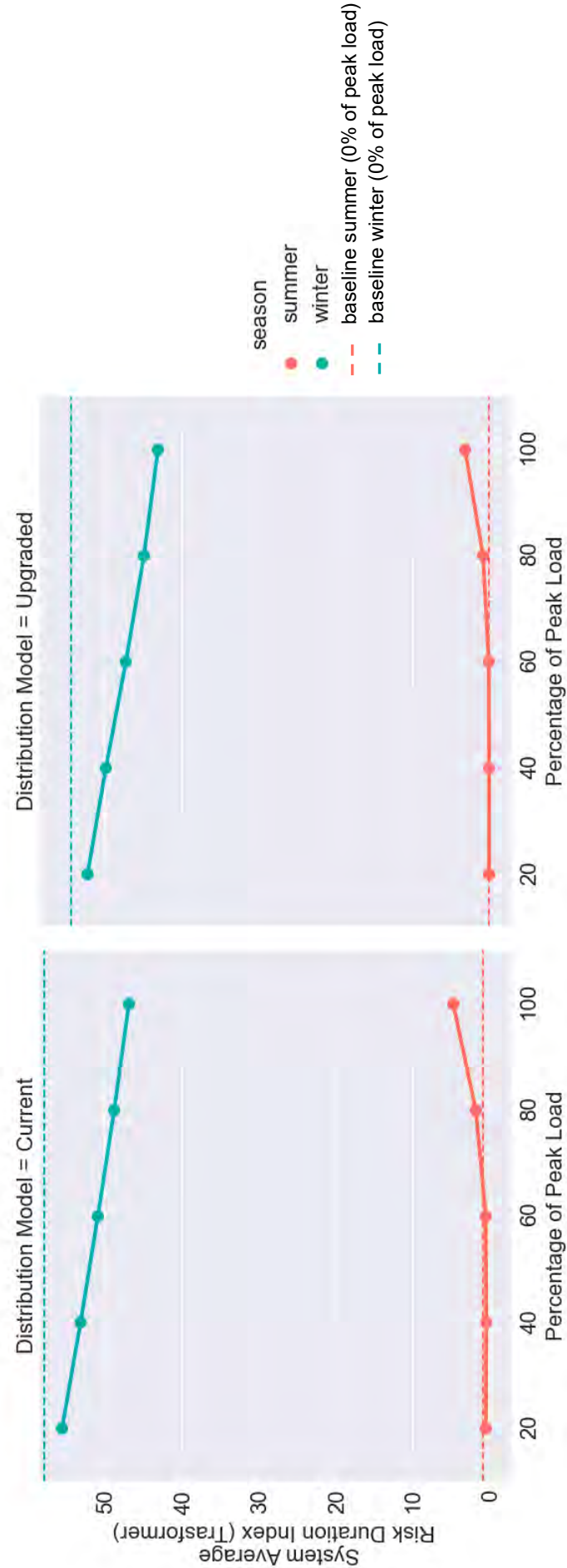
The comparison plots below show that adding energy storage, and enabling larger cost-optimal PV systems increases the benefits we see from DERs in the winter. At the same time, these large PV systems end up increasing risk in the summer at high adoption levels by causing a combination of overvoltages and asset overloading from energy export.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.

# Rooftop Solar and Energy Storage (Future Electrification): SARDI Transformer

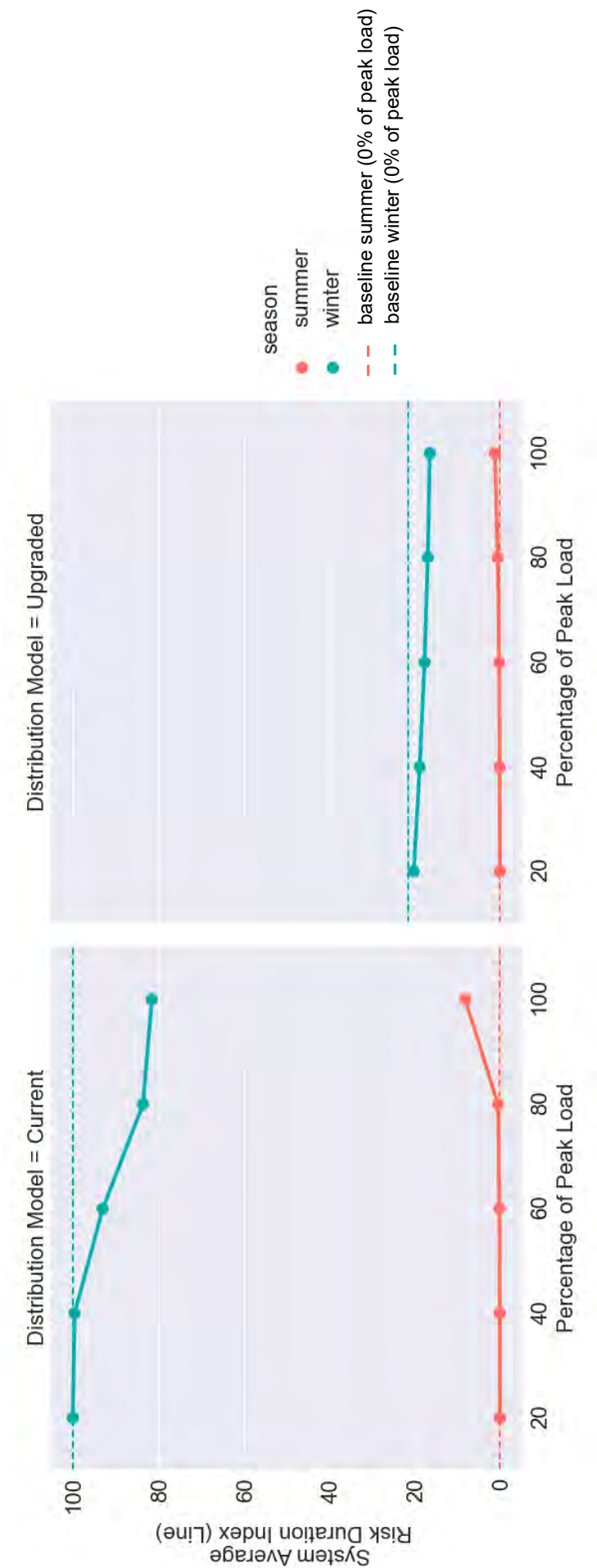
When breaking down our SARDI Aggregated, we see similar trends across each of the more specific SARDI metrics, generally decreasing risk in the winter, and increasing risk in the summer at high levels of adoption. For SARDI Transformer, we see only a small change when upgrading the feeder, given the relatively minor changes that were made to transformer sizes.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.

## Rooftop Solar and Energy Storage (Future Electrification): SARDI Line

For SARDI Line, we see a much more substantial improvement when upgrading the feeder with larger conductors and a higher voltage class, though as with the previous solar-only scenario, there are remaining violations on the upgraded system.

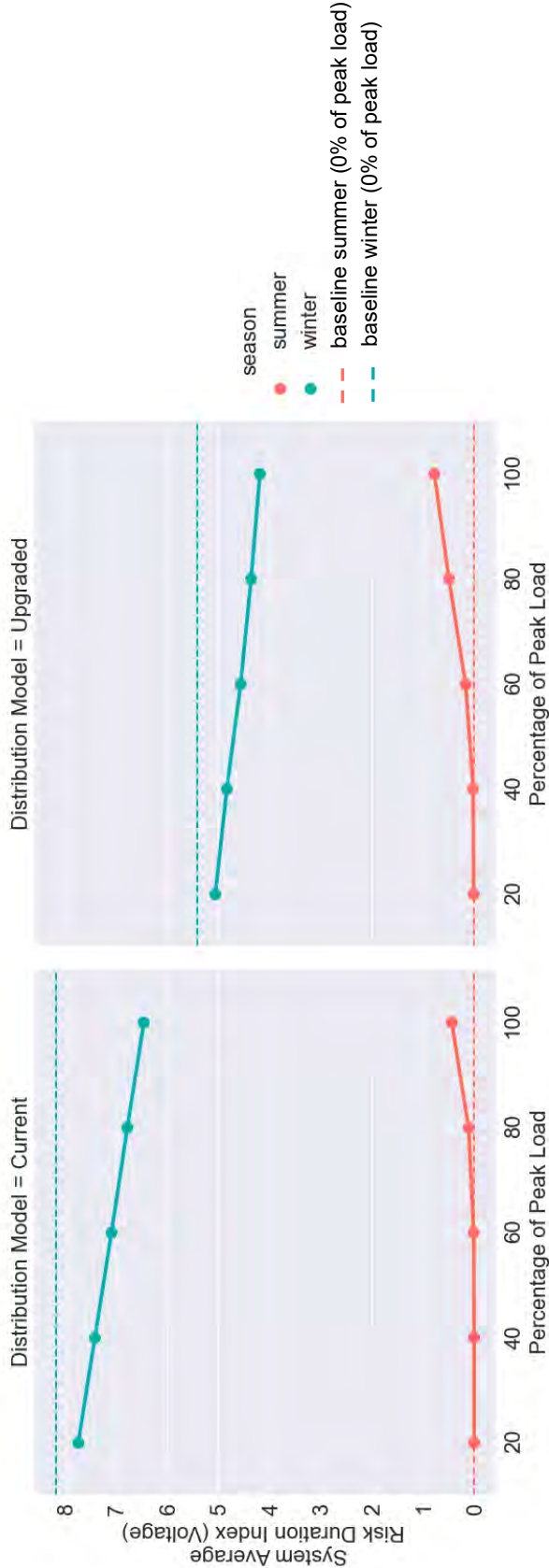


Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.



# Rooftop Solar and Energy Storage (Future Electrification): SARDI Voltage

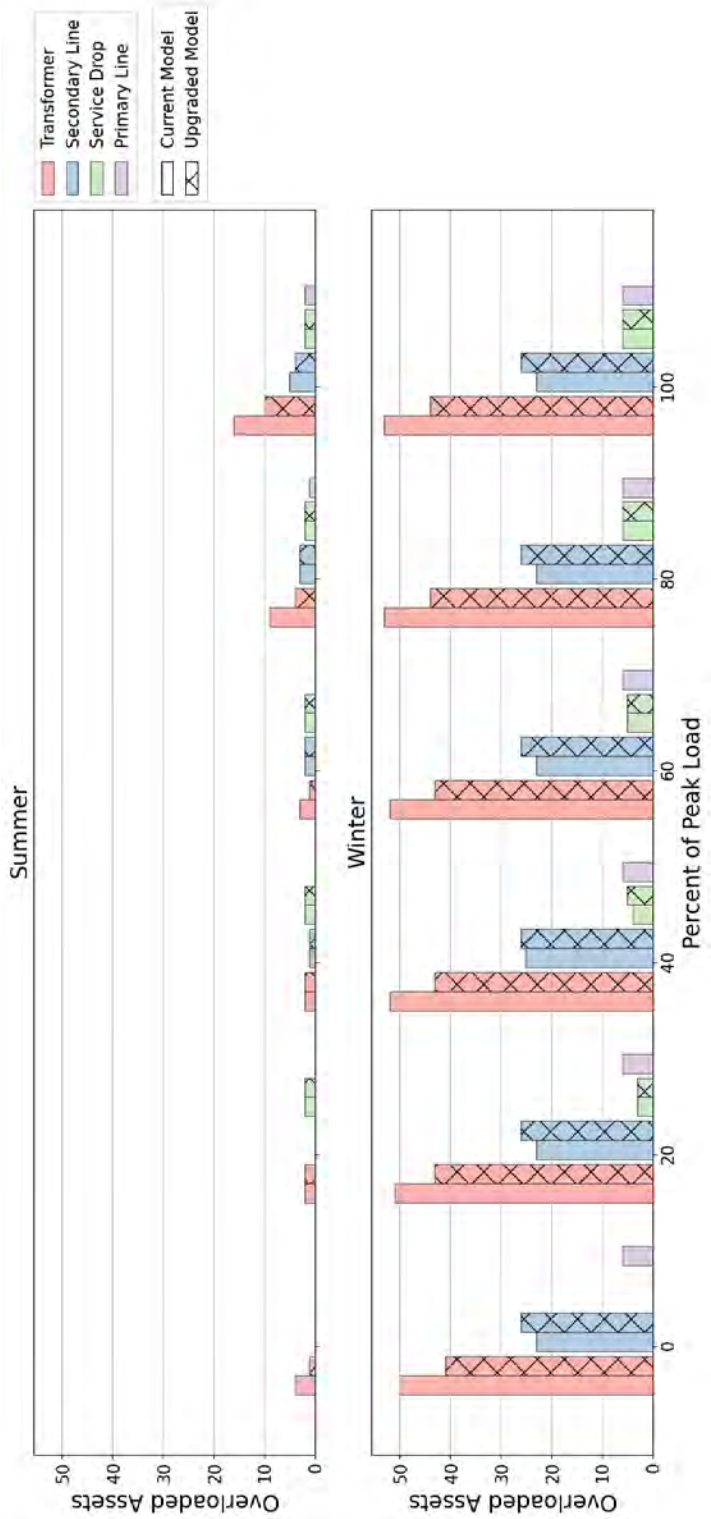
We see improvements in SARDI Voltage on the upgraded model, though some risks remain. A key distinction to be made here is that while the voltage violations in the wintertime are mostly *undervoltages* due to high loading and *improve* with additional distributed generation, the voltage violations in the summer are *overvoltages*, resultant from high amounts of solar export during periods of low load and worsen with additional generation. This is a great example of how distributed generation can both alleviate grid issues or cause them, depending on the pre-existing conditions that exist.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.

## Rooftop Solar and Energy Storage (Future Electrification): Number of Overloaded Assets

Adding energy storage to our solar-only scenario produces only small changes in the number of overloaded assets. We do begin to see a rise in overloads during the summer at high levels of DER adoption, due to the larger PV systems and increased export, as illustrated by our SARDI graphs on previous slides.

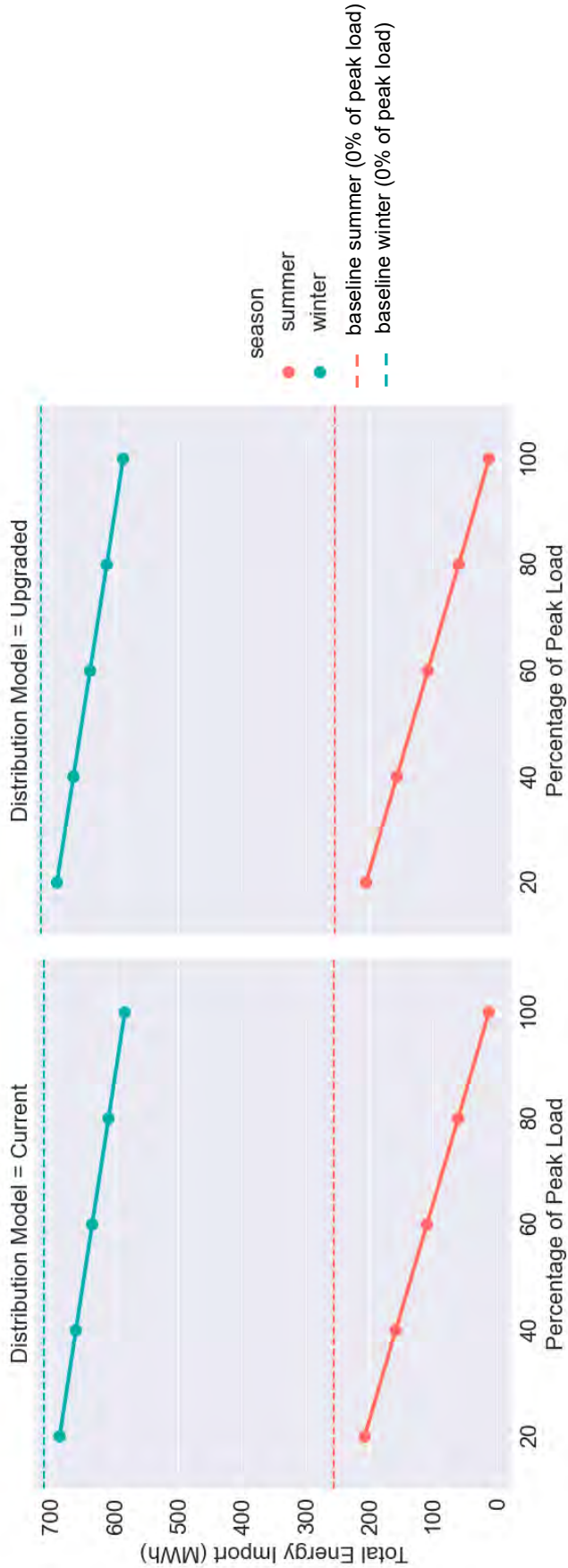


Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.



## Rooftop Solar and Energy Storage (Future Electrification): Total Energy Import

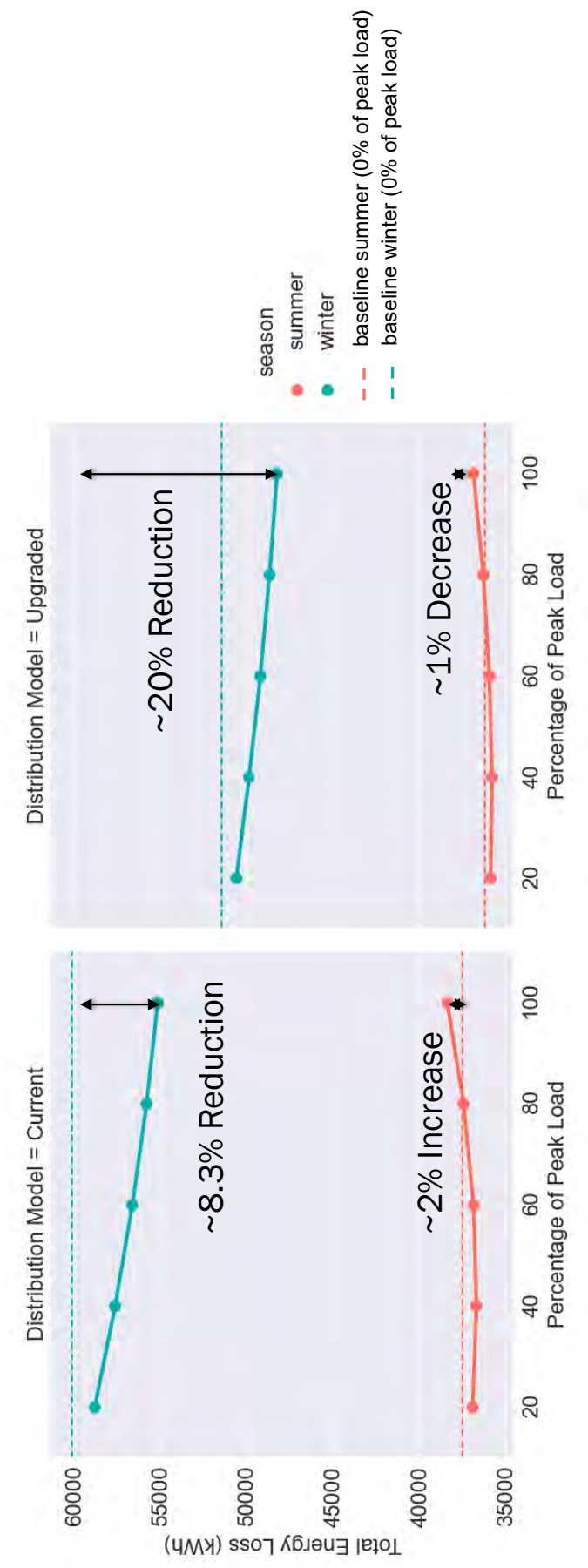
As we increase DER adoption we see energy import decline, so much so that in the summer, imports almost reach zero. While this does not mean no energy produced from bulk generation was consumed on this feeder, it means that the *net* consumption is almost zero. At times, the aggregate distributed generation on this feeder was likely exporting to the bulk system (i.e., reverse power flow at the substation) and at other times, energy was imported from the bulk power system.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.

# Rooftop Solar and Energy Storage (Future Electrification): System Losses

Overall, we see a larger reduction in losses in the winter, compared to our solar-only model, given the larger PV systems and ability to meet 100% of the peak load in installed solar capacity. We also see a net increase in losses at high adoption levels in the summer due to the higher solar export.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.

## Key Takeaways

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- Adding battery storage allows for a larger cost-optimal rooftop solar installation at each house, alleviating the saturation effect we saw in the previous solar-only scenarios, and allowing for more significant improvements in system risk at higher levels of adoption.
- Improvements in system risk due to solar and storage adoption are seen in the wintertime, while high levels of solar adoption start to increase risk during the summertime, due to the increased export of distributed generation.
- Again, upgrading the system results in significant risk reduction, though issues in the form of overloaded secondary assets and transformers remain. Upgrading the system also reduces the negative impacts of high amounts of DER adoption seen in the summertime.
- Substantial loss reduction is seen in both models in the wintertime, though increases in losses are seen at high adoption rates in the summertime, resulting from increased export of distributed generation.
- The remaining risk levels in our upgraded model indicate the need for more robust secondary design standards.

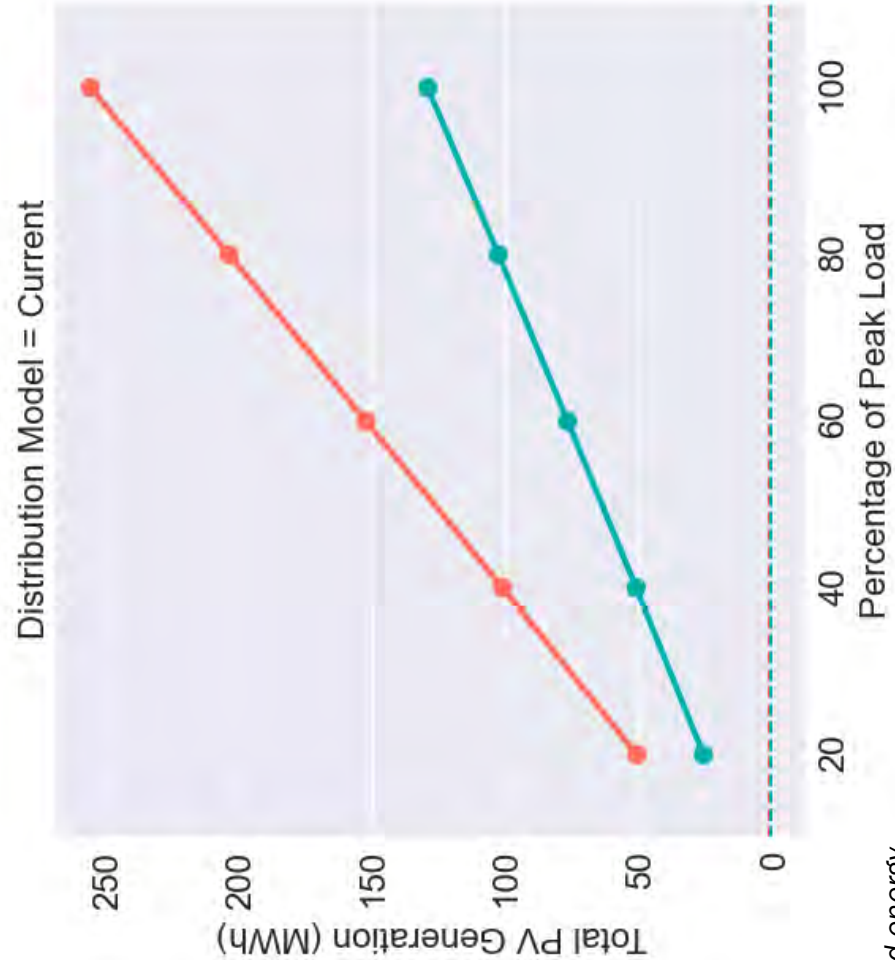
# **Rooftop Solar, Energy Storage and Electric Vehicles (Future Electrification): Grid Impacts**

## Rooftop Solar, Energy Storage, and Electric Vehicles (Future Electrification): Notes

The impacts of electric vehicles (EVs) largely depend on the time of day when customers charge. If charging lines up with solar generation, this has the potential to reduce grid impacts of both technologies, whereas if EV charging times line up with peak electric heating, this has the potential to exacerbate the grid issues of both technologies.

The following analysis assumes an 80%/20% split of level 1 (1.2 kW) and level 2 (7.6 kW) chargers, respectively. The difference in peak power demand between the two charger sizes is substantial. As a result, a high percentage of level 1 chargers only may not produce substantial additional risks when compared with building electrification. Alternatively, if a large number of level 2 chargers are installed, this would have a much more substantial impact, and may prove to be a larger concern than electric heating. At each adoption level plotted, EV chargers are installed at the same locations as those with solar and storage.

The addition of EVs does not change the algorithms or multipliers used to size solar or energy storage systems at these premises. As such, the solar generation plot to the right is identical to that of the solar + storage scenario prior.

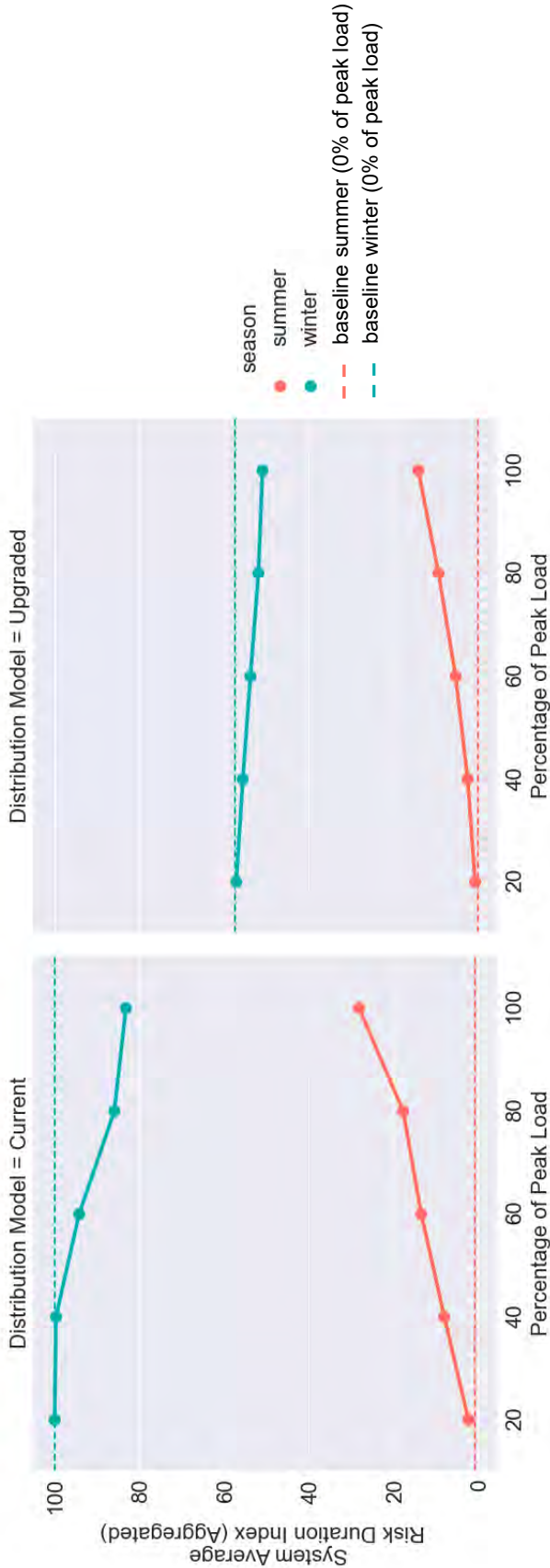


Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.



## Rooftop Solar, Energy Storage, and Electric Vehicles (Future Electrification): SARDI Aggregated

Adding the 80%/20% mix of level 1 and level 2 chargers results in almost no change in aggregated risk in the winter. This indicates that EV charging loads, as we have modeled them, for the most part, do not line up with peak heating hours and that over the modeled timeframe, building electrification presents greater risks. During the summer, we see a marked increase in risk, given the absence of any other electrification impacts. The persistent risks in our Upgraded Model indicate design standards which are not robust enough to accommodate high electrification or EV adoption, again almost exclusively on the secondary systems.

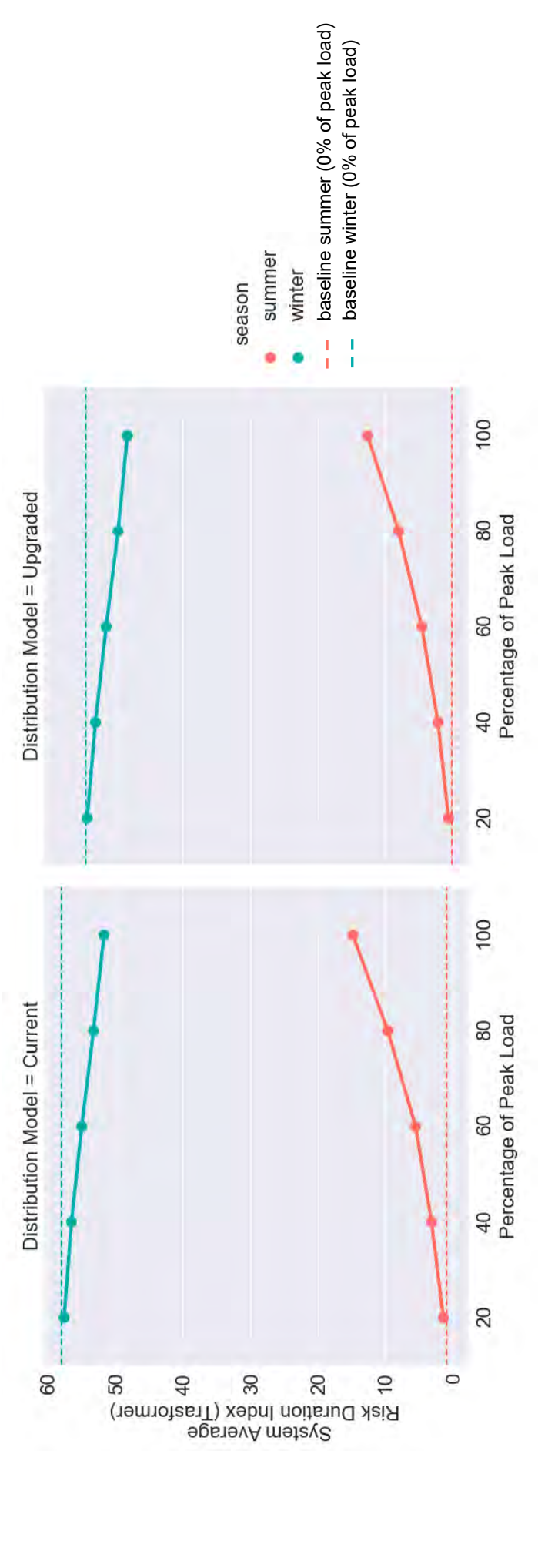


Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.



## Rooftop Solar, Energy Storage, and Electric Vehicles (Future Electrification): SARDI Transformer

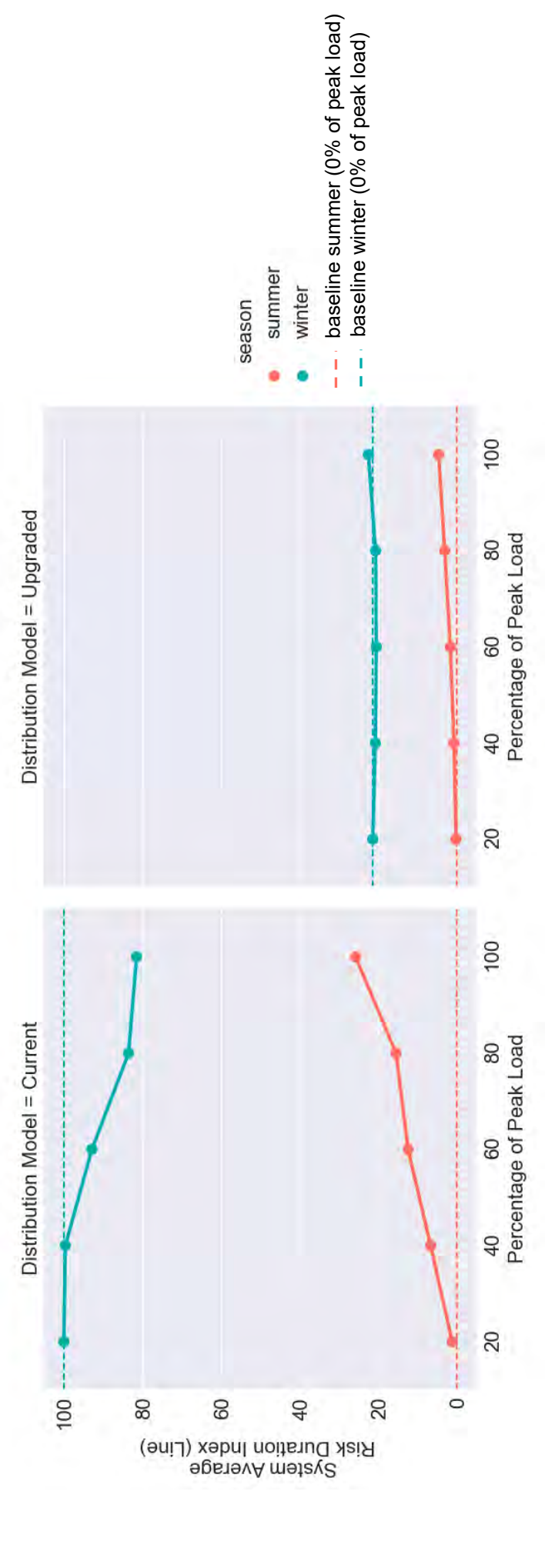
The winter trends largely mirror those in our solar-only and solar and energy storage scenarios, whereas in the summer we see a more substantial increase in risk to transformers with increasing adoption levels.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.

## Rooftop Solar, Energy Storage, and Electric Vehicles (Future Electrification): SARDI Line

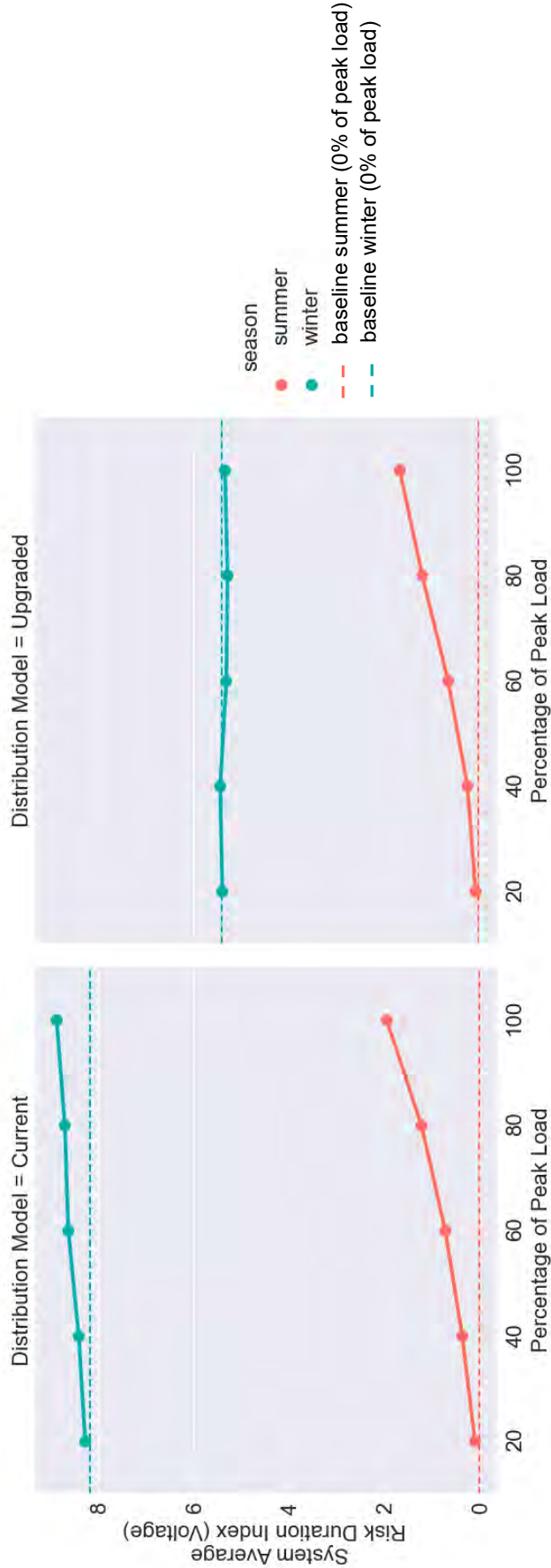
The SARDI Line metric for this scenario again looks very similar to those for the solar and energy storage scenario during the winter months, though there is slightly less of a risk improvement in our Upgraded Model. This indicates that at high levels of EV adoption, we start to see increases in risk that are not being mitigated by the presence of distributed generation and/or energy storage. Similar to the other SARDI metrics, we see an increase in risk from EV adoption in the summer across both the Current and Upgraded Models.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.

## Rooftop Solar, Energy Storage, and Electric Vehicles (Future Electrification): SARDI Voltage

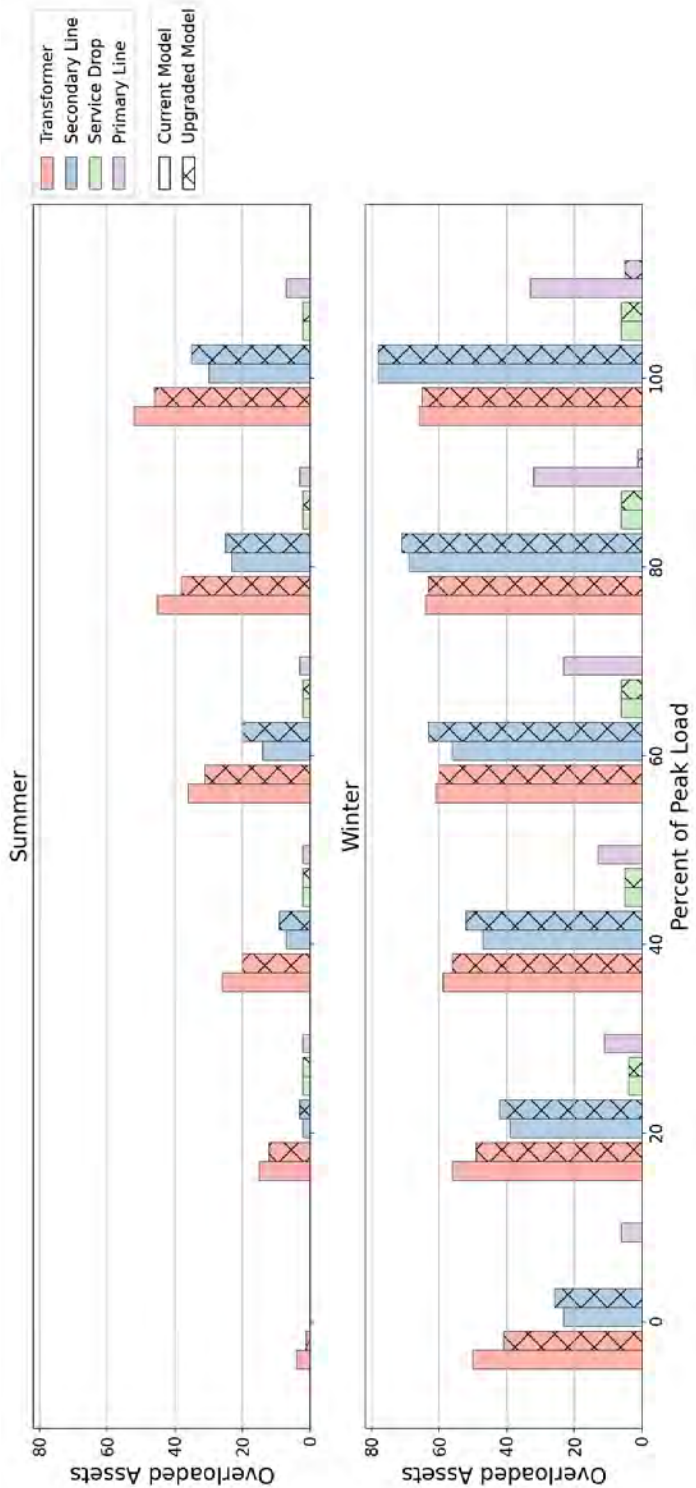
While our aggregated SARDI metric trends down in the winter, our SARDI Voltage trends *up* in our Current Model. Given that this is opposite to what we saw in our solar and energy storage scenario, this is likely a result of undervoltages occurring during charging hours. This may be a result of times when charging hours overlap with heating hours. The steeper increase in voltage violations in the summer, compared with the previous scenarios is indicative that there may be a combination of both overvoltages from solar export and undervoltages from EV charging loads.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.

## Rooftop Solar, Energy Storage, and Electric Vehicles (Future Electrification): Number of Overloaded Assets

The results below show a substantial increase in the number of overloaded assets in both the summer and winter months compared with our solar + energy storage scenario.

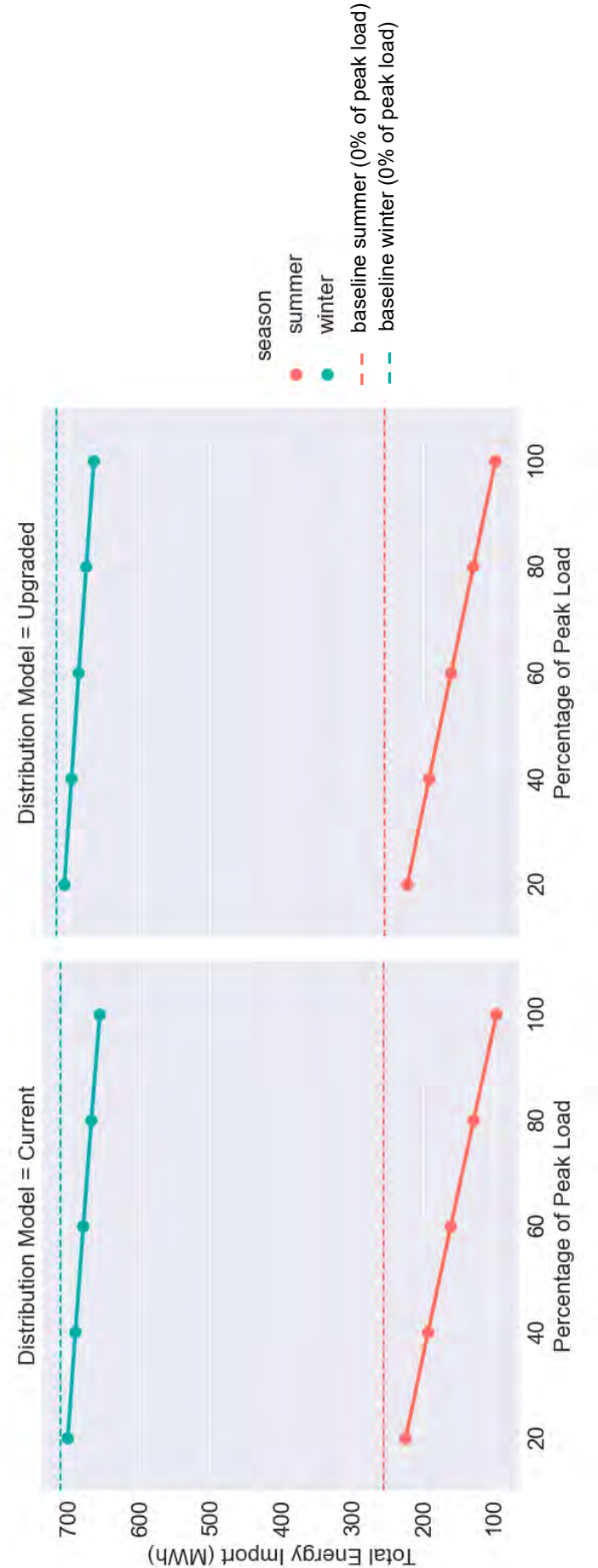


Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.



## Rooftop Solar, Energy Storage, and Electric Vehicles (Future Electrification): Total Energy Import

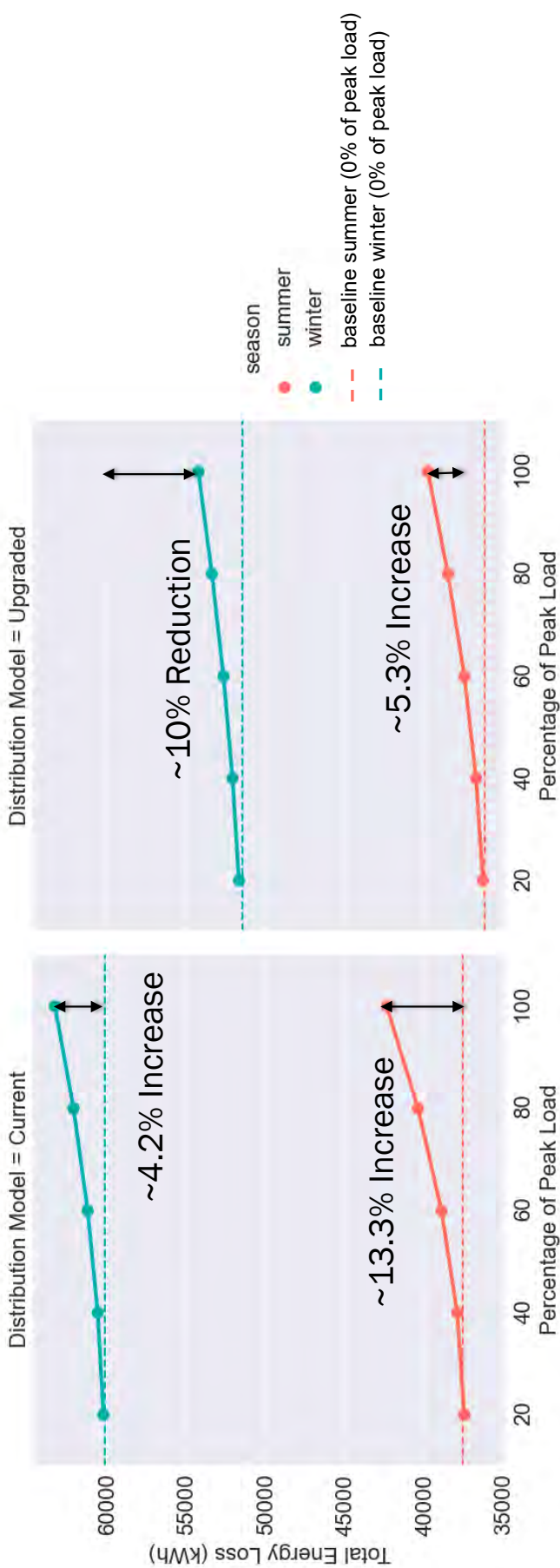
Compared with our previous scenario, we see a flatter, but still downward slope to our energy import. While added distributed generation decreases overall energy imports, this effect is partially offset by the added loads from increasing electric vehicle adoption at the same households.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.

## Rooftop Solar, Energy Storage, and Electric Vehicles (Future Electrification): System Losses

Contrary to all other scenarios evaluated within this study, here we see an increase in losses, in both seasons, across both models as DER adoption increases. That said, we still see a net reduction in our wintertime Upgraded Model when compared to the baseline in our Current Model.



Percentage of Peak Load is defined as % of peak load before introducing distributed energy resources. The line plots shown take the average values across 25 simulation samples.



## Key Takeaways

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- Our modeled EV adoption assumes an 80%/20% split of level 1 and level 2 chargers, respectively. Level 1 chargers have a peak charging demand of 1.2 kW, while level 2 chargers can charge at a peak of 7.6 kW.
- EV charging patterns are modeled using NREL's EVOLVE tool, approximating customer behaviors and typical coincidence of charging demand across the region of Highland Park.
- The addition of EV chargers further exacerbates system risk, with notable increases in risk during the summertime at high adoption levels.
- The added demand from EV charging results in increased system losses. This increase is likely reduced, but not entirely offset, by the addition of distributed generation from rooftop solar.
- Our upgraded model shows less, but still significant levels of risk, indicating the need for revised design standards to accommodate the modeled levels of DER/EV adoption.

## Risk Metrics Summary Table

| Analysis Scenarios<br>*Battery sizing is based on 24-hour outage survival<br>resilience objective |  | SARDI<br>Aggregated<br>(100% Average)<br>(Summer/Winter) | SARDI<br>Transformer<br>(100% Average)<br>(Summer/Winter) | SARDI<br>Line<br>(100% Average)<br>(Summer/Winter) | SARDI<br>Voltage<br>(100% Average)<br>(Summer/Winter) |
|---------------------------------------------------------------------------------------------------|--|----------------------------------------------------------|-----------------------------------------------------------|----------------------------------------------------|-------------------------------------------------------|
| Baseline Risk, Current Model, Base Electrification                                                |  | 0.64/0.54                                                | 0.64/0.54                                                 | 0.00/0.00                                          | 0.00/0.00                                             |
| Solar Only, Current Model, Base Electrification                                                   |  | 0.42/0.51                                                | 0.41/0.50                                                 | 0.01/0.01                                          | 0.00/0.00                                             |
| Solar Battery, Current Model, Base Electrification                                                |  | 0.33/0.43                                                | 0.33/0.43                                                 | 0.00/0.01                                          | 0.00/0.00                                             |
| Baseline Risk, Upgraded Model, Base Electrification                                               |  | 0.02/0.00                                                | 0.00/0.00                                                 | 0.00/0.00                                          | 0.02/0.00                                             |
| Solar Only, Upgraded Model, Base Electrification                                                  |  | 0.22/0.20                                                | 0.16/0.17                                                 | 0.13/0.10                                          | 0.03/0.02                                             |
| Solar Battery, Upgraded Model, Base Electrification                                               |  | 0.12/0.11                                                | 0.05/0.06                                                 | 0.07/0.08                                          | 0.02/0.01                                             |
| Baseline Risk, Current Model, Future Electrification                                              |  | 0.87/100.00                                              | 0.87/57.87                                                | 0.00/100.00                                        | 0.00/8.17                                             |
| Solar Only, Current Model, Future Electrification                                                 |  | 0.47/98.82                                               | 0.44/54.12                                                | 0.02/98.26                                         | 0.01/7.62                                             |
| Solar Battery, Current Model, Future Electrification                                              |  | 10.17/83.16                                              | 4.67/46.82                                                | 8.11/81.50                                         | 0.44/6.45                                             |
| Baseline Risk, Upgraded Model, Future Electrification                                             |  | 0.085/57.44                                              | 0.075/54.31                                               | 0.00/21.44                                         | 0.01/5.40                                             |
| Solar Only, Upgraded Model, Future Electrification                                                |  | 0.23/53.20                                               | 0.18/50.53                                                | 0.14/19.35                                         | 0.04/4.98                                             |
| Solar Battery, Upgraded Model, Future Electrification                                             |  | 4.24/45.48                                               | 3.14/43.05                                                | 1.18/16.42                                         | 0.78/4.18                                             |
| Solar Battery EV, Current Model, Future Electrification                                           |  | 28.11/83.18                                              | 14.75/51.63                                               | 25.68/81.47                                        | 1.93/8.87                                             |
| Solar Battery EV, Upgraded Model, Future Electrification                                          |  | 14.13/50.92                                              | 12.59/48.17                                               | 4.56/22.46                                         | 1.66/5.33                                             |

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# Estimate of Upgrade Costs

## Key Considerations for System Upgrade Costs

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- A significant portion of DTE's legacy 4.8 kV distribution system was built nearly a century ago and is in a state of severe decay today. Hardening such a system, while also bringing it up to current construction standards, would likely entail a nearly full rebuild of all distribution assets.
- Beyond the reconductoring, transformer replacements, and modifications to grid topologies represented in this study, some of the more significant cost adders associated with such an upgrade include a full substation rebuild, replacement of poles and crossarms, vegetation management, increasing the number and size of service transformers, implementing grid modernization technologies, and the labor.
- Further study is required to estimate the cost of system-wide upgrade needs specific to Highland Park. Components listed on slide 13 are the minimum upgrades necessary to study the impact of an upgraded 13.2 kV system but does not include costs for other necessary infrastructure.
- As part of a comprehensive rebuild, it would be advantageous to also incorporate modern grid technologies (e.g., SCADA, grid automation, modern system protection, etc.) to ensure superior reliability in the long run and contribute to wider grid modernization initiatives.
- For such a comprehensive upgrade as described above, DTE's estimate is \$2.4–\$3.0 million per mile.<sup>1</sup>
- This project did not estimate the total length/size of DTE's distribution system in Highland Park. This grid impact analysis only considered a portion of the Highland Park distribution network (see slide 10).

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<sup>1</sup> Wang, Joy. "DTE Electric 4.8kV Technical Conference," n.d. <https://www.michigan.gov/mpsc/consumer/electricity/dte-electric-4-8kv-technical-conference>.



# Thank You

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DOE/GO-102024-6110 • March 2024



|                                                                                                                 |        |                                                                                                                                                |
|-----------------------------------------------------------------------------------------------------------------|--------|------------------------------------------------------------------------------------------------------------------------------------------------|
| Social cost of carbon in 2020 \$                                                                                | \$190  | Table ES-1 in EPA Social Cost of Carbon Report, Exhibit 284 (pdf p. 10); 2% discount rate value used                                           |
| Annual increase in SCC, 2020 \$                                                                                 | \$4    |                                                                                                                                                |
| 2020 to 2021 CPI                                                                                                | 1.047  | Federal Reserve Ex. 282                                                                                                                        |
| Social cost of carbon in 2021 \$                                                                                | \$199  |                                                                                                                                                |
| Annual increase in SCC, 2021 \$                                                                                 | \$4.19 |                                                                                                                                                |
| Michigan CO2 mt/MWh, 2022                                                                                       | 0.50   | Table 7 Michigan Electricity Profile, Exhibit 263                                                                                              |
| Value in 2040 CO2/MWh, assumed                                                                                  | 0.00   | Approximate value based on Table 3 in Michigan Electricity Work Group, Exhibit 285 and explanations in the text of Witness Makhijani testimony |
| Discount rate                                                                                                   | 5.64%  | NREL REopt Exhibit 278, Slide 15                                                                                                               |
| Food saved per year per HH/y                                                                                    | \$100  |                                                                                                                                                |
| # of HH Ford Center                                                                                             | 90     | Based on 2.2 people per household and 200 people; the latter figure is From NREL REopt, Exhibit 278, Slide 47                                  |
| # of HH Parker V                                                                                                | 28     | NREL REopt Exhibit 278, Slide 60                                                                                                               |
| Shelter value per night per HH                                                                                  | \$100  |                                                                                                                                                |
| Number of nights per year                                                                                       | 2      |                                                                                                                                                |
| <b>Inputs for Parker Village into LBNL Interruption Cost Estimator calculator</b>                               |        |                                                                                                                                                |
| SAIDI, minutes/year                                                                                             | 563    | Source: Reliability performance table, pdf p. 3, DTE, Exhibit 287                                                                              |
| SAIFI, avg. outages per year                                                                                    | 1.37   | Source: Reliability performance table, pdf p. 3, DTE, Exhibit 287                                                                              |
| Residences                                                                                                      | 28     | NREL REopt Exhibit 278, slide 60                                                                                                               |
| Businesses                                                                                                      | 5      | NREL REopt, Exhibit 278, Slide 60 and see the note below                                                                                       |
| Post resilience SAIFI, outages per year                                                                         | 1      |                                                                                                                                                |
| Post resilience SAIDI, minutes/year                                                                             | 30     |                                                                                                                                                |
| Note: Building B is 3 businesses for a total of 6 business customers based on NREL REopt, Exhibit 278, Slide 57 |        |                                                                                                                                                |
| For modeling purposes, I have used 5 businesses - see testimony                                                 |        |                                                                                                                                                |



Source: Estimated from data in Exhibit 278 first year PV output, using an annual output degradation of 0.5%  
The output in year 25 is about 88% of the initial output. An average value of 94% of the first year's output is used for the calculations

| Resilience case                      | Capacity, kW | First year output, kWh | Average over 25 years, kWh/year |
|--------------------------------------|--------------|------------------------|---------------------------------|
| Residential, one house               | 4.62         | 5,944                  | 5,587                           |
| Commercial building                  | 60.5         | 80,113                 | 75,306                          |
| Ford Recreation Center               | 100          | 131,756                | 123,851                         |
| Parker Village, solar + battery case | 2626.5       | 3,460,574              | 3,252,940                       |
| Parker Village, solar + diesel case  | 202.89       | 267,320                | 251,281                         |

|                                                              |     |
|--------------------------------------------------------------|-----|
| Average output per year over 25 years relative to first year | 94% |
|--------------------------------------------------------------|-----|

Social Cost of Carbon calculations; See Inputs tab for inputs  
Cumulative value used for benefit of avoided CO2 emissions

| Year                                                 | 2022   | 2023  | 2024  | 2025  | 2026  | 2027  | 2028  | 2029  | 2030  | 2031  | 2032  |
|------------------------------------------------------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Michigan elec. grid CO2 emissions, mt/MWh            | 0.50   | 0.47  | 0.44  | 0.41  | 0.39  | 0.36  | 0.33  | 0.30  | 0.28  | 0.25  | 0.22  |
| Annual reduction in emissions CO2 mt/MWh             | 0.0276 |       |       |       |       |       |       |       |       |       |       |
| Social cost of carbon \$/mt                          | \$207  | \$211 | \$216 | \$220 | \$224 | \$228 | \$232 | \$237 | \$241 | \$245 | \$249 |
| Present value in 2026 per MWh of solar, 2021 dollars |        |       |       |       | \$82  | \$73  | \$77  | \$72  | \$66  | \$61  | \$55  |

**Cumulative NPV per MWh of carbon-free generation, 2025 to 2050** **\$689**

Note: the period 2040 to 2050 contributes nothing to avoided social cost of carbon since the grid is assumed to have zero CO2emissions after 2040

|       |       |       |       |       |       |       |       |
|-------|-------|-------|-------|-------|-------|-------|-------|
| 2033  | 2034  | 2035  | 2036  | 2037  | 2038  | 2039  | 2040  |
| 0.19  | 0.17  | 0.14  | 0.11  | 0.08  | 0.06  | 0.03  | 0     |
|       |       |       |       |       |       |       |       |
| \$253 | \$258 | \$262 | \$266 | \$270 | \$274 | \$279 | \$283 |
| \$49  | \$43  | \$36  | \$29  | \$22  | \$15  | \$8   | \$0   |

Table from NREL REopt modeling, Exhibit 278. Data and results from slide numbers indicated for each resilience case.  
Non-resilience cases are not included here

|                                                                 | Solar/battery/<br>diesel<br>size,kW/kWh/<br>kW | Monthly net<br>benefit<br>(cost),<br>\$/month<br>(Note 1) | Benefit/(cost)<br>per home,<br>\$/month (Note<br>2) | % of year<br>protection,<br>long outages | Comment                               |
|-----------------------------------------------------------------|------------------------------------------------|-----------------------------------------------------------|-----------------------------------------------------|------------------------------------------|---------------------------------------|
| Typical residential building<br>2,200 sq. ft.), Slide 31        | 4.62/27.7/0                                    | (\$28.65)                                                 | (\$28.65)                                           | 97% (24 hr)                              |                                       |
| Typical commercial Building<br>(33,000 sq. ft.), Slide 32       | 60.25/44.9/0                                   | \$55.67                                                   | N/A                                                 | 96% (24-hr)                              |                                       |
| Ernest T. Ford Recreation<br>Center, solar+battery, Slide<br>48 | 100/1,110.5/0                                  | (\$1,383.34)                                              | (\$15.37)                                           | 96% (72-hr)                              | hub for 90<br>homes                   |
| Ernest T. Ford Recreation<br>Center, solar +diesel              | 100/0/69                                       | (\$151.87)                                                | (\$1.69)                                            | 100% (72-hr)                             | hub for 90<br>homes                   |
| Parker Village, solar+battery,<br>slide 67                      | 6.85/8,990.3/0                                 | (\$13,528.23)                                             | (\$193.26)                                          | 96% (72 hr);<br>91% (120-hr)             | 28 homes<br>(assigned 40%<br>of cost) |
| Parker Village, solar +diesel                                   | 202.89/0/684                                   | (\$1,837.55)                                              | (\$26.25)                                           | 100% (72-hr);<br>95% (120-hr)            | 28 homes<br>(assigned 40%<br>of cost) |

Note 1: this is calculated by dividing the NREL NPV value over 25 years by 300, the number of months in 25 years.

Note 2: This is calculated by dividing the total monthly NPV value by the number of homes for which the building provides resilience services

**Calculations below are by Arjun Makhijani based on inputs in the other worksheets and the data in the table above**

Net present value (NPV) of resilience cases without and with benefits included

|                                                    | Annual solar<br>generation<br>MWh/y | Avoided<br>social cost of<br>carbon | Food saved<br>benefit | Shelter value | 25-year NPV<br>benefit (cost)<br>from NREL, no<br>non-energy<br>benefits | Net 25-year<br>NPV benefit<br>(cost) with<br>benefits,<br>rounded |
|----------------------------------------------------|-------------------------------------|-------------------------------------|-----------------------|---------------|--------------------------------------------------------------------------|-------------------------------------------------------------------|
| Typical residential building<br>2,200 sq. ft.)     | 5.6                                 | \$3,850                             | \$1,300               | \$2,600       | (\$8,596)                                                                | (\$800)                                                           |
| Typical commercial Building<br>(33,000 sq. ft.)    | 75                                  | \$51,896                            | N/A                   | N/A           | \$16,700                                                                 | \$68,600                                                          |
| Ernest T. Ford Recreation<br>Center, solar+battery | 124                                 | \$85,349                            | \$117,000             | \$238,200     | (\$415,002)                                                              | \$25,500                                                          |
| Ernest T. Ford Recreation<br>Center, solar +diesel | 124                                 | \$85,349                            | \$117,000             | \$238,200     | (\$45,561)                                                               | \$395,000                                                         |
| Parker Village, solar+battery                      | 3,253                               | \$2,241,696                         | \$36,400              | \$74,100      | (\$4,058,469)                                                            | (\$1,706,300)                                                     |
| Parker Village, solar +diesel                      | 267                                 | \$184,218                           | \$36,400              | \$74,100      | (\$551,265)                                                              | (\$256,500)                                                       |

Net present value (NPV) of Parker Village resilience cases including social cost of carbon and avoided cost of all outages

|                               | Carbon<br>benefit | ICE<br>calculated<br>benefits<br>(Note 1) | NREL NPV, no<br>benefits, slide<br>67 | Net NPV,<br>avoided CO2 +<br>outage cost |
|-------------------------------|-------------------|-------------------------------------------|---------------------------------------|------------------------------------------|
| Parker Village, solar+battery | \$2,241,696       | \$1,257,486                               | (\$4,058,469)                         | (\$559,287)                              |
| Parker Village, solar +diesel | \$184,218         | \$1,257,486                               | (\$551,265)                           | \$890,439                                |

Note 1. This assumes that

- The outages over 25 years would be at the rate of the five-year 2018-2022 average
- Post resilience outages are one outage at 30 minutes per year
- Starting year for benefit calculations 2026

FRED Graph Observations  
Federal Reserve Economic Data  
Link: <https://fred.stlouisfed.org>  
Help: <https://fredhelp.stlouisfed.org>  
Economic Research Division  
Federal Reserve Bank of St. Louis

CPIAUCSL Consumer Price Index for All Urban Consumers: All Items in U.S. City Average, Index 1982-1984=100, Annual, Seasonally Adjusted

Frequency: Annual

| observation_date | CPIAUCSL |
|------------------|----------|
| 1947-01-01       | 22.332   |
| 1948-01-01       | 24.045   |
| 1949-01-01       | 23.809   |
| 1950-01-01       | 24.063   |
| 1951-01-01       | 25.973   |
| 1952-01-01       | 26.567   |
| 1953-01-01       | 26.768   |
| 1954-01-01       | 26.865   |
| 1955-01-01       | 26.796   |
| 1956-01-01       | 27.191   |
| 1957-01-01       | 28.113   |
| 1958-01-01       | 28.881   |
| 1959-01-01       | 29.150   |
| 1960-01-01       | 29.585   |
| 1961-01-01       | 29.902   |
| 1962-01-01       | 30.253   |
| 1963-01-01       | 30.633   |
| 1964-01-01       | 31.038   |
| 1965-01-01       | 31.528   |
| 1966-01-01       | 32.471   |
| 1967-01-01       | 33.375   |
| 1968-01-01       | 34.792   |
| 1969-01-01       | 36.683   |
| 1970-01-01       | 38.842   |
| 1971-01-01       | 40.483   |
| 1972-01-01       | 41.808   |
| 1973-01-01       | 44.425   |
| 1974-01-01       | 49.317   |
| 1975-01-01       | 53.825   |
| 1976-01-01       | 56.933   |
| 1977-01-01       | 60.617   |
| 1978-01-01       | 65.242   |
| 1979-01-01       | 72.583   |
| 1980-01-01       | 82.383   |
| 1981-01-01       | 90.933   |
| 1982-01-01       | 96.533   |
| 1983-01-01       | 99.583   |
| 1984-01-01       | 103.933  |
| 1985-01-01       | 107.600  |
| 1986-01-01       | 109.692  |
| 1987-01-01       | 113.617  |
| 1988-01-01       | 118.275  |
| 1989-01-01       | 123.942  |
| 1990-01-01       | 130.658  |
| 1991-01-01       | 136.167  |
| 1992-01-01       | 140.308  |
| 1993-01-01       | 144.475  |
| 1994-01-01       | 148.225  |
| 1995-01-01       | 152.383  |
| 1996-01-01       | 156.858  |
| 1997-01-01       | 160.525  |
| 1998-01-01       | 163.008  |
| 1999-01-01       | 166.583  |
| 2000-01-01       | 172.192  |
| 2001-01-01       | 177.042  |
| 2002-01-01       | 179.867  |
| 2003-01-01       | 184.000  |
| 2004-01-01       | 188.908  |
| 2005-01-01       | 195.267  |
| 2006-01-01       | 201.558  |
| 2007-01-01       | 207.344  |
| 2008-01-01       | 215.254  |
| 2009-01-01       | 214.565  |
| 2010-01-01       | 218.076  |
| 2011-01-01       | 224.923  |
| 2012-01-01       | 229.586  |
| 2013-01-01       | 232.952  |
| 2014-01-01       | 236.715  |
| 2015-01-01       | 237.002  |
| 2016-01-01       | 240.005  |
| 2017-01-01       | 245.121  |
| 2018-01-01       | 251.100  |
| 2019-01-01       | 255.653  |
| 2020-01-01       | 258.846  |
| 2021-01-01       | 270.966  |
| 2022-01-01       | 292.621  |
| 2023-01-01       | 304.701  |
| 2024-01-01       | #N/A     |

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# Does home insurance cover spoiled food from a power outage?

Most homeowners insurance policies will cover the cost of food that spoils due to a covered event, like a power outage after a tornado or hurricane.



By [Rachael Brennan](#)

Edited by [Jennifer Gimbel](#)

Updated May 30, 2024 | 4 min read

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1. [When does homeowners insurance cover spoiled food?](#)
2. [Is there a deductible for food spoilage?](#)
3. [When does homeowners insurance not cover spoiled food?](#)



- If your food spoils because of a power outage caused by a windstorm, lightning strike, or another covered peril, [homeowners insurance](#) can help pay to replace your food. Most standard homeowners insurance policies cover up to \$500 in food loss after a power outage, but only if the cause of the outage is covered by your policy.

Homeowners insurance doesn't cover maintenance issues, so if your food spoils because your refrigerator suddenly stops working, your policy won't cover the loss. If your utility company causes a power outage, you might be able to get them to reimburse you for the food loss, however it'll depend on the situation and company.

## Key takeaways

- Some insurance companies provide **up to \$500** in food spoilage coverage to cover the cost of food loss after power outages
- If your food spoils due to a power outage that is caused by a **covered peril**, this coverage can reimburse you for the loss
- Home insurance won't reimburse you for food loss caused by an **earthquake power outage or a broken refrigerator**
- If food spoilage coverage is not included in your home insurance, you can likely **add it to your policy for an additional premium**

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## What does homeowners insurance cover?

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#### Home insurance calculator: Estimate rates by ZIP code

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## When does homeowners insurance cover spoiled food?

Most homeowners insurance policies include coverage for frozen and refrigerated food that spoils during a power outage if the loss of power was caused by a covered peril.

Here are two examples when your home insurance would cover spoiled food:

**Lightning strikes your house** and causes a power surge that fries your refrigerator.

**A windstorm blows down a tree in your yard and** knocks out power to your home, including your refrigerator.

However, if an electrical grid failure caused the power outage and food loss, your insurer may not be the one picking up the tab. In this instance, it's worth asking your utility company if they're able to pay for the loss. Some utility companies provide food spoilage reimbursements in instances where they're at fault for the outage, so check with yours to see if this is the case.

### Ready to shop home insurance?

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## What does food spoilage insurance cover?

Food spoilage insurance covers the loss of frozen or refrigerated food that goes bad due to a power outage caused by a covered peril. However, it doesn't cover dry goods like flour, sugar, or canned foods that are tainted.

## Does homeowners insurance cover food loss from a broken refrigerator?

If your refrigerator is broken because of a covered peril, like a lightning strike or a kitchen fire, your insurance will likely pay a food spoilage claim. However, the insurance company won't pay for your claim if your refrigerator breaks because of a non-covered peril like age or wear and tear.

## Is there a deductible for food spoilage?

Every company is different, but the odds are good your policy deductible applies to most claims, including food spoilage. When you file a food spoilage claim some insurers will require you to pay a deductible before they cover the remainder of the loss. If your deductible exceeds the cost of the spoiled food, you won't be able to file a claim. In some cases, insurance companies will waive the deductible or offer a separate, lower deductible for food losses.

Food spoilage coverage typically has a limit of \$500, which is the maximum amount your insurer will pay out for food loss. However, some insurance companies may offer higher food spoilage coverage limits of up to \$2,500 or more.

## When does homeowners insurance not cover spoiled food?

A standard home insurance policy lists out the named perils that are excluded from coverage. If a power outage is caused by a flood, for example, you won't be reimbursed for any food loss or other damage to your home and personal property.

Power outages caused by any of the following events are also excluded:

Earthquakes or any form of earth movement

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Wear and tear over time

Certain causes of a power surge, like poor installation

Equipment breakdown, like if your refrigerator suddenly goes kaput

For additional protection for your appliances, like your refrigerator or washing machine, consider adding [equipment breakdown coverage](#) to your policy for an additional premium. Equipment breakdown coverage is an [endorsement you can add on to your homeowners insurance](#) to cover appliances that break down due to mechanical or electrical failure. If your fridge was installed wrong or happens to stop working after a power surge, equipment breakdown coverage would cover repairs or to replace it, and may even cover food spoilage as well.

## How to file a food spoilage claim

When submitting a claim for food loss, you'll need to provide proof and documentation just as you would with any other personal property claim. It's a good idea to have the following information handy:

Receipts or bank statements of the food purchase

Pictures or videos of the damage that caused the loss and of the spoiled food itself

An estimated cost of the food if you don't have all the receipts

You can typically file a claim with your homeowners insurance company over the phone or online through their website. If your claim is approved, a claims adjuster may visit your home to investigate the damage and confirm the legitimacy of your loss before reaching a settlement.

#### Does business insurance cover spoiled food?

Businesses that have refrigerated food on site, like restaurants and food trucks, may need to purchase a spoilage coverage endorsement to protect themselves financially from the loss of refrigerated or frozen food that is part of their stock.

### Ready to shop home insurance?

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## What is considered food spoilage?

According to the United States Department of Agriculture (USDA), food spoilage is considered food that has deteriorated to the point of developing an unpleasant odor, taste, or texture. This may mean the food has become slimy, mushy, or smelly, and that most people would choose not to eat it. <sup>[1]</sup>

However, food does not need to be inedible or dangerous to be considered spoiled. Food that has deteriorated to a point that it has an unappealing scent, flavor, or texture is considered spoiled, even if it wouldn't make you sick to eat it.

### What are examples of spoiled food?

There are many ways for food to spoil, but only *some* types of spoilage are covered by your homeowners insurance.

#### Spoiled food that would be covered by insurance

Dairy items, like milk and cheese, that develop a foul odor after a power outage

Meat and poultry items, like chicken and beef, that are stored at inappropriate temperatures due to a power outage and cannot safely be eaten

Frozen items that lose their structure if not kept cold, like ice cream and popsicles, that have melted after a power outage

#### Spoiled food that would NOT be covered by insurance

Dry goods, like rice and flour, that are damaged due to flooding or storage in a wet or humid environment

#### Table of contents

Frozen, refrigerated, or dry goods that are spoiled due to chemical contamination, such as exposure to bleach or other chemicals used to clean up after a covered peril

#### How long is food good in the refrigerator without power?

According to the USDA, refrigerated foods stored at temperatures above 40 F for more than two hours should be discarded.<sup>[2]</sup> This means most refrigerators can keep everything at a safe temperature for up to four hours after a power outage, but this depends on a variety of factors, including the age, condition, and make and model of your refrigerator.

If you have any reason to think your refrigerator or freezer got too warm during a power outage, the safest thing to do is throw out everything and restock your refrigerator with new items. You may be able to be reimbursed for the lost food if the power outage that led to the spoilage was caused by a covered peril.

#### Ready to shop home insurance?

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#### References

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November 2023



**Supplementary Material for the Regulatory  
Impact Analysis for the Final Rulemaking,  
“Standards of Performance for New,  
Reconstructed, and Modified Sources and  
Emissions Guidelines for Existing Sources: Oil  
and Natural Gas Sector Climate Review”**

EPA Report on the Social Cost of Greenhouse  
Gases: Estimates Incorporating Recent Scientific  
Advances



# **Report on the Social Cost of Greenhouse Gases:**

## **Estimates Incorporating Recent Scientific Advances**

November 2023

National Center for Environmental Economics  
Office of Policy

Climate Change Division  
Office of Air and Radiation

U.S. Environmental Protection Agency  
Washington, DC 20460



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## List of Abbreviations

|                  |                                                                                   |
|------------------|-----------------------------------------------------------------------------------|
| AR               | Assessment Report of the United Nations Intergovernmental Panel on Climate Change |
| BRICK            | Building Blocks for Relevant Ice and Climate Knowledge                            |
| CH <sub>4</sub>  | Methane                                                                           |
| CCAPM            | Consumption-based Capital Asset Pricing Model                                     |
| CIAM             | Coastal Impact and Adaptation Model                                               |
| CMIP             | Coupled Model Intercomparison Project                                             |
| CO <sub>2</sub>  | Carbon Dioxide                                                                    |
| DICE             | Dynamic Integrated Climate and Economy                                            |
| DSCIM            | Data-driven Spatial Climate Impact Model                                          |
| ESM              | Earth System Models                                                               |
| ECS              | Equilibrium Climate Sensitivity                                                   |
| E.O.             | Executive Order                                                                   |
| FACTS            | Framework for Assessing Changes To Sea-level                                      |
| FaIR             | Finite Amplitude Impulse Response                                                 |
| FrEDI            | Framework for Evaluating Damages and Impacts                                      |
| FUND             | Climate Framework for Uncertainty, Negotiation, and Distribution                  |
| GHG              | Greenhouse Gas                                                                    |
| GDP              | Gross Domestic Product                                                            |
| GIVE             | Greenhouse Gas Impact Value Estimator                                             |
| GMSL             | Global Mean Sea Level                                                             |
| GMST             | Global Mean Surface Temperature                                                   |
| IAM              | Integrated Assessment Model                                                       |
| IWG              | Interagency Working Group on the Social Cost of Greenhouse Gases                  |
| MAGICC           | Model for the Assessment of Greenhouse Gas Induced Climate Change                 |
| MER              | Market Exchange Rate                                                              |
| N <sub>2</sub> O | Nitrous Oxide                                                                     |
| PAGE             | Policy Analysis of the Greenhouse Gas Effect                                      |
| PPP              | Purchasing Power Parity                                                           |
| RC               | Reduced Complexity                                                                |
| RCP              | Representative Concentration Pathway                                              |
| SC               | Social Cost                                                                       |
| SLR              | Sea Level Rise                                                                    |
| SP               | Socioeconomic Projections                                                         |
| SSP              | Shared Socioeconomic Pathways                                                     |
| TCR              | Transient Climate Response                                                        |

## Executive Summary

This report presents new estimates of the social cost of carbon (SC-CO<sub>2</sub>), social cost of methane (SC-CH<sub>4</sub>), and social cost of nitrous oxide (SC-N<sub>2</sub>O), collectively referred to as the “social cost of greenhouse gases” (SC-GHG). These estimates reflect recent advances in the scientific literature on climate change and its economic impacts and incorporate recommendations made by the National Academies of Science, Engineering, and Medicine (National Academies 2017). The SC-GHG allows analysts to incorporate the net social benefits of reducing emissions of greenhouse gases (GHG), or the net social costs of increasing GHG emissions, in benefit-cost analysis and, when appropriate, in decision-making and other contexts. The SC-GHG is the monetary value of the net harm to society from emitting a metric ton of that GHG into the atmosphere in a given year. In principle, the SC-GHG is a comprehensive metric that includes the value of all future climate change impacts (both negative and positive), including changes in net agricultural productivity, human health effects, property damage from increased flood risk, changes in the frequency and severity of natural disasters, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services. The SC-GHG, therefore, also reflects the societal net benefit of reducing emissions of the GHG by a metric ton. The SC-GHG is the theoretically appropriate value to use when conducting benefit-cost analyses of policies that affect GHG emissions. In practice, data and modeling limitations restrain the ability of SC-GHG estimates to include all physical, ecological, and economic impacts of climate change, implicitly assigning a value of zero to the omitted climate damages. The estimates are, therefore, a partial accounting of climate change impacts and likely underestimate the marginal benefits of abatement.

Since 2008, the EPA has used estimates of the SC-GHG in analyses of actions that affect GHG emissions. The values used by the EPA from 2009 to 2016, and since 2021, have been consistent with those developed and recommended by the Interagency Working Group on the SC-GHG (IWG), and the values used from 2017-2020 were consistent with those required by Executive Order (E.O.) 13783. During that time, the National Academies conducted a comprehensive review of the SC-CO<sub>2</sub> and issued a final report in 2017 recommending specific criteria for future updates to the SC-CO<sub>2</sub> estimates, a modeling framework to satisfy the specified criteria, and both near-term updates and longer-term research needs pertaining to various components of the estimation process. The IWG was reconstituted in 2021 and E.O. 13990 directed it to develop a comprehensive update of its SC-GHG estimates, recommendations regarding areas of decision-making to which SC-GHG should be applied, and a standardized review and updating process to ensure that the recommended estimates continue to be based on the best available economics and science going forward.

The EPA is a member of the IWG and is participating in the IWG’s work under E.O. 13990. While that process continues, this EPA report presents a set of SC-GHG estimates that incorporates numerous methodological updates that address the near-term recommendations of the National Academies. The report takes a modular approach. The methodology underlying each of the four components, or modules, of the SC-GHG estimation process – socioeconomics and emissions, climate, damages, and discounting – is developed by drawing on the latest research and expertise from the scientific disciplines relevant to that component. The socioeconomic and emissions module relies on a new set of probabilistic projections for population, income, and GHG emissions developed under the Resources for the Future (RFF) Social Cost of Carbon Initiative (Rennert et al. 2022a). The climate module relies on the Finite Amplitude Impulse

Response (FaIR) model (Millar et al. 2017; Smith et al. 2018, IPCC 2021b), a widely used Earth system model recommended by the National Academies, which captures the relationships between GHG emissions, atmospheric GHG concentrations, and global mean surface temperature. The socioeconomic projections and outputs of the climate module are inputs into the damage module to estimate monetized future damages from climate change. Based on a review of available studies and approaches to damage function estimation, the report uses three separate damage functions to form the damage module. They are:

1. a subnational-scale, sectoral damage function (based on the Data-driven Spatial Climate Impact Model (DSCIM) developed by the Climate Impact Lab (CIL 2023, Carleton et al. 2022, Rode et al. 2021)),
2. a country-scale, sectoral damage function (based on the Greenhouse Gas Impact Value Estimator (GIVE) model developed under RFF's Social Cost of Carbon Initiative (Rennert et al. 2022b)), and
3. a meta-analysis-based damage function (based on Howard and Sterner (2017)).

The discounting module discounts the stream of future net climate damages back to the year of emissions using a set of dynamic discount rates that have been calibrated following the Newell et al. (2022) approach, as applied in Rennert et al. (2022a, 2022b). This approach uses the Ramsey (1928) discounting formula in which the parameters are calibrated such that (1) the decline in the certainty-equivalent discount rate matches the latest empirical evidence on interest rate uncertainty estimated by Bauer and Rudebusch (2020, 2023) and (2) the average of the certainty-equivalent discount rate over the first decade matches a near-term consumption rate of interest. Uncertainty in the starting rate is addressed by using three near-term target rates (1.5%, 2.0%, and 2.5%) based on multiple lines of evidence on observed real market interest rates. This approach results in dynamic discount rate paths and is consistent with the National Academies (2017) recommendation to use three sets of Ramsey parameters that reflect a range of near-term certainty-equivalent discount rates and are consistent with theory and empirical evidence on consumption rate uncertainty. Finally, the value of aversion to risk associated with net damages from GHG emissions is explicitly incorporated into the modeling framework following the economic literature.

Taken together, the methodologies adopted in this report allow for a more holistic treatment of uncertainty than in past estimates by the EPA. The updates incorporate a quantitative consideration of uncertainty into all modules and use a Monte Carlo approach that captures the compounding uncertainties across modules. The estimation process generates nine separate distributions of discounted marginal damages per metric ton – the product of using three damage modules and three near-term target discount rates – for each gas in each emissions year. These distributions have long right tails reflecting the extensive evidence in the scientific and economic literature that shows the potential for lower-probability but higher-impact outcomes from climate change, which would be particularly harmful to society. The uncertainty grows over the modeled time horizon. Therefore, under cases with a lower near-term target discount rate – that give relatively more weight to impacts in the future – the distribution of results is wider. To produce a range of estimates that reflects the uncertainty in the estimation exercise while also providing a manageable number of estimates for policy analysis, this report combines the multiple lines of evidence on damage modules by averaging the results across the three damage module specifications. Table ES.1 summarizes the averaged certainty-equivalent SC-GHG estimates that can be used to value GHG emissions changes in benefit-cost analysis. The table presents the SC-CO<sub>2</sub>, SC-CH<sub>4</sub>, and SC-N<sub>2</sub>O estimates under each near-term discount rate for emissions years 2020 through 2080.



The methodological updates implemented in this report represent a major step forward in bringing SC-GHG estimates closer to the frontier of climate science and economics and address near-term updating recommendations from the National Academies' (2017). Nevertheless, the SC-GHG estimates presented in this report still have several limitations, as would be expected for any modeling exercise that covers such a broad scope of scientific and economic issues across a complex global landscape. There are still many categories of climate impacts and associated damages that are only partially—or not at all—reflected in these estimates and sources of uncertainty that have not been fully characterized due to data and modeling limitations. For example, the modeling in this report omits most of the consequences of changes in precipitation, damages from extreme weather events, the potential for nongradual damages from passing critical thresholds (e.g., tipping elements) in natural or socioeconomic systems, and non-climate mediated effects of GHG emissions other than CO<sub>2</sub> fertilization (e.g., ocean acidification due to CO<sub>2</sub> emissions, tropospheric ozone formation due to CH<sub>4</sub> emissions). Importantly, this update does not yet reflect interaction effects and feedback effects within, and across, natural and human systems. For example, it does not explicitly reflect potential interactions among damage categories, such as those stemming from the interdependencies of energy, water, and land use. These interactions and feedbacks, and others, were highlighted by the National Academies as an important area of future research for longer-term enhancements in the SC-GHG estimation framework.

Given both the methodological choices and the modeling limitations, primarily the numerous categories of damages that are currently unrepresented, the resulting SC-GHG estimates presented in this report likely underestimate the marginal damages from GHG pollution. The EPA will continue to review developments in the literature, including more robust methodologies for estimating the magnitude of the various direct and indirect damages from GHG emissions, and look for opportunities to further improve SC-GHG estimation going forward.

To ensure that the methodological updates adopted in this report are consistent with economic theory and reflect the latest science, the EPA initiated an external peer review panel to conduct a high-quality technical review, completed in May 2023. The peer reviewers commended the agency on its development of this update, calling it a much-needed improvement in estimating the SC-GHG and a significant step towards addressing the National Academies' recommendations with defensible modeling choices based on current science. The peer reviewers provided numerous recommendations for refining the presentation and for future modeling improvements, especially with respect to climate change impacts and associated damages that are not currently included in the analysis. Additional discussion of omitted impacts and other updates have been incorporated to address peer reviewer recommendations. Complete information about the external peer review, including the peer reviewer selection process, the final report with individual recommendations from peer reviewers, and the EPA's response to each recommendation is available at: <https://www.epa.gov/environmental-economics/scghg-td-peer-review>.<sup>1</sup>

---

<sup>1</sup> In addition, the EPA solicited public comment on the use of the updated SC-GHG estimates and the external review draft of this report in the docket for EPA's December 2022 Supplemental Notice of Proposed Rulemaking, "Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil

*Table ES.1: Estimates of the Social Cost of Greenhouse Gases (SC-GHG), 2020-2080 (2020 dollars)*

| SC-GHG and Near-term Ramsey Discount Rate |                                                                         |      |      |                                                                         |       |       |                                                                          |         |         |
|-------------------------------------------|-------------------------------------------------------------------------|------|------|-------------------------------------------------------------------------|-------|-------|--------------------------------------------------------------------------|---------|---------|
| Emission<br>Year                          | SC-CO <sub>2</sub><br>(2020 dollars per metric ton of CO <sub>2</sub> ) |      |      | SC-CH <sub>4</sub><br>(2020 dollars per metric ton of CH <sub>4</sub> ) |       |       | SC-N <sub>2</sub> O<br>(2020 dollars per metric ton of N <sub>2</sub> O) |         |         |
|                                           | Near-term rate                                                          |      |      | Near-term rate                                                          |       |       | Near-term rate                                                           |         |         |
|                                           | 2.5%                                                                    | 2.0% | 1.5% | 2.5%                                                                    | 2.0%  | 1.5%  | 2.5%                                                                     | 2.0%    | 1.5%    |
| 2020                                      | 120                                                                     | 190  | 340  | 1,300                                                                   | 1,600 | 2,300 | 35,000                                                                   | 54,000  | 87,000  |
| 2030                                      | 140                                                                     | 230  | 380  | 1,900                                                                   | 2,400 | 3,200 | 45,000                                                                   | 66,000  | 100,000 |
| 2040                                      | 170                                                                     | 270  | 430  | 2,700                                                                   | 3,300 | 4,200 | 55,000                                                                   | 79,000  | 120,000 |
| 2050                                      | 200                                                                     | 310  | 480  | 3,500                                                                   | 4,200 | 5,300 | 66,000                                                                   | 93,000  | 140,000 |
| 2060                                      | 230                                                                     | 350  | 530  | 4,300                                                                   | 5,100 | 6,300 | 76,000                                                                   | 110,000 | 150,000 |
| 2070                                      | 260                                                                     | 380  | 570  | 5,000                                                                   | 5,900 | 7,200 | 85,000                                                                   | 120,000 | 170,000 |
| 2080                                      | 280                                                                     | 410  | 600  | 5,800                                                                   | 6,800 | 8,200 | 95,000                                                                   | 130,000 | 180,000 |

Values of SC-CO<sub>2</sub>, SC-CH<sub>4</sub>, and SC-N<sub>2</sub>O are rounded to two significant figures. The annual unrounded estimates are available in Appendix A.5 and at: <https://www.epa.gov/environmental-economics/scghg>.

and Natural Gas Sector Climate Review.” All the public comments and EPA’s responses to the comments are available in the rule docket at: <https://www.regulations.gov/docket/EPA-HQ-OAR-2021-0317>.

# 1 Background

A robust and scientifically founded assessment of the positive and negative impacts that an action can be expected to have on society facilitates evidence-based policy making. Estimates of the social cost of carbon (SC-CO<sub>2</sub>), social cost of methane (SC-CH<sub>4</sub>), and social cost of nitrous oxide (SC-N<sub>2</sub>O) allow analysts to incorporate the net social benefits of reducing emissions of each of these greenhouse gases, or the net social costs of increasing such emissions, in benefit-cost analysis, and when appropriate, in decision making and other contexts.<sup>2</sup> Collectively, these values are referred to as the “social cost of greenhouse gases” (SC-GHG) in this document. The SC-GHG is the monetary value of the future stream of net damages associated with adding one ton of that GHG to the atmosphere in a given year. The SC-GHG, therefore, also reflects the societal net benefit of reducing emissions of the gas by one ton. The social benefits of abatement are an aggregated measure of the affected individuals’ willingness to pay to avoid those damages. The SC-GHG is the marginal social benefit of GHG abatement and is, therefore, the theoretically appropriate value to use when conducting benefit-cost analyses of policies that affect GHG emissions.<sup>3</sup> The marginal social cost will differ by the type of GHG (such as CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O)<sup>4</sup> and by the year in which the emissions change occurs.

In principle, the SC-GHG is a comprehensive metric that includes the value of all climate change impacts (both negative and positive), including (but not limited to) changes in net agricultural productivity, human health effects, property damage from increased flood risk, changes in the frequency and severity of natural disasters, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services. In practice, because of data and modeling limitations, which prevent full representation of harmful climate impacts, estimates of the SC-GHG—including the updated values presented in this report—are a partial accounting of climate change impacts and, as such, lead to underestimates of the marginal benefits of abatement.

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<sup>2</sup> Note, for example, that EPA has recommended use of SC-GHG estimates in environmental impact statements under NEPA when appropriate. See, e.g., Letter from EPA to USPS, on the Final Environmental Impact Statement for Next Generation Delivery Vehicle Acquisitions, Feb. 2, 2022.

<sup>3</sup> These estimates of social damages should not be confused with the estimated costs of attaining a predetermined emissions or warming limit. Specifically, there is another strand of research that investigates the costs of setting a specific climate target (e.g., capping emissions or temperature increases to a certain level). The expected marginal cost of GHG abatement associated with meeting a specific climate target can be useful in evaluating policy cost-effectiveness but is not an alternative way to value damages from GHG emissions in benefit-cost analysis. For more on how these concepts (e.g., a predetermined target-based approach and a damage (SC-GHG) based approach) can be used when designing climate policy and in policy evaluation, see, for example, Hänsel et al. (2020); Stern et al. (2022); Aldy et al. (2021); and Gundlach and Livermore (2022).

<sup>4</sup> SC-GHG estimates are gas specific because one metric ton of CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, or other GHG differ in the temporal pathway of their impact on society, through both climate mediated effects of emissions (temperature, sea level rise, etc.) and non-climate mediated effects of emissions (e.g., carbon fertilization effects and ocean acidification due to CO<sub>2</sub> emissions, tropospheric ozone formation due to CH<sub>4</sub> emissions). See Marten and Newbold (2012), Waldhoff et al. (2014), and IWG (2016b) for more discussion.

## 1.1 Overview of SC-GHG Estimates Used in EPA Analyses to Date

The academic literature has published estimates of the social cost of carbon and other GHGs since at least the early 1990s. As early as 2002 researchers began conducting reviews that combined lines of evidence across early SC-CO<sub>2</sub> estimates (Clarkson and Deyes 2002). The EPA began regularly incorporating SC-CO<sub>2</sub> estimates in regulatory impact analyses following a 2008 court ruling in which an agency was ordered to consider the SC-CO<sub>2</sub> in the rulemaking process. Specifically, the U.S. Ninth Circuit Court of Appeals remanded a fuel economy rule to the Department of Transportation for failing to consider the value of reducing CO<sub>2</sub> emissions when determining the appropriate level of the fuel economy standard, stating that “while the record shows that there is a range of values, the value of carbon emissions reduction is certainly not zero.”<sup>5</sup> The SC-CO<sub>2</sub> estimates initially presented in EPA analyses in 2008 and early 2009 were derived from the academic literature.<sup>6</sup>

Beginning in September 2009, EPA’s regulatory impact analyses applied SC-CO<sub>2</sub> estimates that were developed through a U.S. Government interagency working group (IWG) process. The IWG was launched in early 2009, under the leadership of the Office of Management and Budget (OMB) and the Council of Economic Advisers (CEA), to ensure that Federal agencies had access to the best available information when quantifying the benefits of reducing CO<sub>2</sub> emissions in benefit-cost analyses. The IWG included technical experts from the EPA and other federal agencies. The IWG first developed an interim set of SC-CO<sub>2</sub> estimates based on an average of estimates published in the peer reviewed academic literature.<sup>7</sup> The EPA chose to use these interim estimates in multiple regulatory impact analyses and sought public comments to inform the estimates for future use.<sup>8</sup> In 2010, the IWG published a Technical Support Document (TSD) with a set of four updated SC-CO<sub>2</sub> estimates recommended for use in regulatory analyses in addition to guidance on using the estimates (IWG 2010). Three of these values were based on the average SC-CO<sub>2</sub> from three widely cited integrated assessment models (IAMs) in the peer-reviewed literature – DICE, PAGE, and FUND<sup>9</sup> – at constant discount rates of 2.5%, 3%, and 5%. The fourth value

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<sup>5</sup> *Ctr. for Biological Diversity v. Nat’l Highway Traffic Safety Admin.*, 538 F.3d 1172, 1200 (9th Cir. 2008).

<sup>6</sup> For more information, see “Technical Support Document on Benefits of Reducing GHG Emissions” (<https://www.regulations.gov/document/EPA-HQ-OAR-2008-0318-0078>), prepared for EPA’s July 2008 Advanced Notice of Proposed Rulemaking for Regulating Greenhouse Gas Emissions Under the Clean Air Act, and EPA’s May 2009 Regulatory Impact Analysis for the Renewable Fuel Standard Program (RFS2) Proposed Rule (EPA 2008).

<sup>7</sup> The IWG used a meta-analysis of SC-CO<sub>2</sub> estimates (Tol 2008) as the starting point for the development of the interim estimates recommended in 2009. With that starting point, the IWG filtered the existing SC-CO<sub>2</sub> estimates in the meta-analysis by using those that (1) were derived from peer-reviewed studies; (2) did not weight the monetized damages to one country more than those in other countries (i.e., no equity weighting); (3) used a “business as usual” climate scenario; and (4) were based on the most recent published version of each of the three major integrated assessment models (IAMs): FUND, PAGE, and DICE. See EPA and DOT (2009) for more discussion of how the filtered estimates were combined to form a set of five recommended interim values.

<sup>8</sup> See, for example, EPA and DOT’s joint September 2009 Proposed Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards (EPA and DOT 2009).

<sup>9</sup> The DICE (Dynamic Integrated Climate and Economy) model by William Nordhaus evolved from a series of energy models and was first presented in 1990 (Nordhaus and Boyer 2000, Nordhaus 2008). The PAGE (Policy Analysis of the Greenhouse Effect) model was developed by Chris Hope in 1991 for use by European decision-makers in

was included to represent the potential for lower-probability, higher-impact outcomes from climate change, that would be particularly harmful to society and thus relevant to the public and policymakers. For this purpose, it selected the SC-CO<sub>2</sub> value for the 95<sup>th</sup> percentile at a 3% discount rate. Absent formal inclusion of risk aversion in the modeling, considering values above the mean in a right skewed distribution with long tails acknowledges society's preference for avoiding risk.

The EPA chose to update the set of SC-CO<sub>2</sub> estimates used in regulatory analyses following a May 2013 update of the IWG SC-CO<sub>2</sub> estimates (IWG 2013). The 2013 IWG SC-CO<sub>2</sub> update incorporated new versions of the IAMs used in the peer-reviewed literature but did not revisit other IWG modeling decisions (i.e., the discount rates or harmonized inputs for socioeconomic and emission scenarios and equilibrium climate sensitivity). Improvements in the way damages are modeled were confined to those that had been incorporated into the latest versions of the models by the developers themselves in the peer-reviewed literature.<sup>10</sup>

In June 2015, the EPA began using estimates of SC-CH<sub>4</sub> and SC-N<sub>2</sub>O from Marten et al. (2015), which were consistent with the methodology underlying the IWG's estimates of the SC-CO<sub>2</sub> estimates. The Marten et al. estimates were first applied in sensitivity analyses in regulatory impact analyses of proposed rulemakings with CH<sub>4</sub> and N<sub>2</sub>O emission impacts.<sup>11</sup> Following the completion of an external peer review of the application of these estimates to federal regulatory analysis, the estimates were used in the main analysis of other proposed rulemakings with CH<sub>4</sub> emissions impacts (EPA 2015a, 2015b).<sup>12</sup> In August 2016, the Marten et al. SC-CH<sub>4</sub> and SC-N<sub>2</sub>O estimates were adopted by the IWG in an addendum to the IWG's TSD (IWG 2016a, 2016b).<sup>13</sup> The IWG recommended these estimates as a method for improving the analyses of regulatory actions that are projected to influence CH<sub>4</sub> or N<sub>2</sub>O emissions in a manner consistent with how CO<sub>2</sub> emission changes were being valued.

Over the course of developing and updating the SC-GHG estimates that have been used in EPA analyses, there were extensive opportunities for public input on the estimates and underlying methodologies. There

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assessing the marginal impact of carbon emissions (Hope 2006, Hope 2008). The FUND (Climate Framework for Uncertainty, Negotiation, and Distribution) model, developed by Richard Tol in the early 1990s, was originally used to study international capital transfers in climate policy and was subsequently widely used to study climate impacts (e.g., Tol 2002a, Tol 2002b, Anthoff et al. 2009, Tol 2009).

<sup>10</sup> The IWG subsequently provided additional minor technical revisions in November of 2013 and July of 2015, as explained in Appendix B of the 2016 TSD (IWG 2016a).

<sup>11</sup> The SC-CH<sub>4</sub> and SC-N<sub>2</sub>O estimates were first used in sensitivity analysis for the Proposed Rulemaking for Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles—Phase 2 (EPA and DOT 2015).

<sup>12</sup> For a discussion of public comments received on the valuation of non-CO<sub>2</sub> GHG impacts in general and the use of the Marten et al. (2015) estimates, see, e.g., EPA (2012a, 2012b, 2016a, 2016b), EPA and DOT (2016).

<sup>13</sup> In 2021, the EPA developed analogous estimates of the social cost of hydrofluorocarbons (SC-HFCs) that are consistent with the methodology underlying the SC-CO<sub>2</sub>, SC-CH<sub>4</sub>, and SC-N<sub>2</sub>O estimates. See, for example, EPA's final Regulatory Impact Analysis for Phasing Down Production and Consumption of Hydrofluorocarbons (HFCs) for more information (EPA 2021a). Similarly, Tan et al. (2023) provides a thorough documentation of the estimation as developed in EPA (2021a), in addition to presenting estimates of the SC-HFCs using an updated version of the GIVE framework.

was a public comment process associated with each proposed EPA rulemaking that used the estimates, and OMB initiated a separate comment process on the IWG TSD in 2013. Commenters offered a wide range of perspectives on all aspects of the process, methodology, and final estimates, and submitted diverse suggestions for improvements. The U.S. Government Accountability Office (GAO) reviewed the development of the IWG SC-CO<sub>2</sub> estimates and concluded that the IWG processes and methods reflected three principles: consensus-based decision making, reliance on existing academic literature and models, and disclosure of limitations and incorporation of new information (GAO 2014).

In 2015, as part of the IWG response to the public comments received in the 2013 solicitation, the IWG announced a National Academies review of the IWG estimates (IWG 2015). Specifically, the IWG asked the National Academies to conduct a multi-discipline, two-phase assessment of the IWG estimates and offer advice on approaching future updates to ensure that the estimates continue to reflect the best available science and methodologies. The National Academies' interim (Phase 1) report (National Academies 2016a) recommended against a near-term update of the SC-CO<sub>2</sub> estimates within the existing modeling framework. For future revisions, the National Academies recommended a broader update of the climate system module consistent with the most recent, best available science and offered recommendations for how to enhance the discussion and presentation of uncertainty in the SC-CO<sub>2</sub> estimates. In addition to publishing estimates of SC-CH<sub>4</sub> and SC-N<sub>2</sub>O, the IWG's 2016 TSD revision responded to the National Academies' Phase 1 report recommendations regarding the presentation of uncertainty. The revisions included: an expanded presentation of the SC-GHG estimates that highlights a symmetric range of uncertainty around estimates for each discount rate; new sections that provide a unified discussion of the methodology used to incorporate sources of uncertainty; a detailed explanation of the uncertain parameters in the FUND and PAGE models; and making the full set of SC-CO<sub>2</sub> estimates easily accessible to the public on OMB's website.

In January 2017, the National Academies released their final report, *Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide* and recommended specific criteria for future updates to the SC-CO<sub>2</sub> estimates, a modeling framework to satisfy the specified criteria, and both near-term updates and longer-term research needs pertaining to various components of the estimation process (National Academies 2017). A description of the National Academies' recommendations for near-term updates is provided in Section 1.2 below. Shortly thereafter, in March 2017, President Trump issued E.O. 13783, which called for the rescission and review of several climate-related Presidential and regulatory actions as well as for a review of the SC-GHG estimates used for regulatory impact analyses. Further, E.O. 13783 disbanded the IWG, withdrew the previous TSDs, and directed agencies to "ensure" SC-GHG estimates used in regulatory analyses "are consistent with the guidance contained in OMB Circular A-4", "including with respect to the consideration of domestic versus international impacts and the consideration of appropriate discount rates" (E.O. 13783, Section 5(c)). The EPA's benefit-cost analyses following E.O. 13783 used SC-GHG estimates that attempted to focus on the specific share of physical climate change impacts occurring in the U.S. as captured by then-available models (which did not reflect many pathways by which climate impacts affect the welfare of U.S. citizens and residents) and were calculated using two default discount rates recommended by OMB Circular A-4 (2003), 3% and 7%. The EPA's regulatory analyses under E.O. 13783 included sensitivity analyses based on global SC-GHG values and using a lower

discount rate of 2.5%.<sup>14</sup> All other methodological decisions and model versions used in SC-GHG calculations under E.O. 13783 remained the same as those used by the IWG in 2010 and 2013, respectively.

On January 20, 2021, President Biden issued E.O. 13990 which re-established an IWG and directed the group to develop an update of the SC-GHG estimates that reflect the best available science and the recommendations of the National Academies (2017). In February 2021, the IWG recommended the interim use of the most recent SC-GHG estimates developed by the IWG prior to the group being disbanded in 2017, adjusted for inflation (IWG 2021). As discussed in the February 2021 TSD, the IWG concluded that these interim estimates reflected the immediate need to have SC-GHG estimates available for agencies to use in regulatory benefit-cost analyses and other applications that were developed using a transparent process, peer reviewed methodologies, and the science available at the time of that process. The February 2021 update also recognized the limitations of the interim estimates and encouraged agencies to use their best judgment in, for example, considering sensitivity analyses using lower discount rates. The IWG published a Federal Register notice on May 7, 2021, soliciting comment on the February 2021 TSD and on how best to incorporate the latest peer-reviewed scientific literature in order to develop an updated set of SC-GHG estimates. The EPA applied the IWG's interim SC-GHG estimates in analyses published following the release of the February 2021 TSD (see, e.g., EPA (2021b, 2021c)).

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<sup>14</sup>OMB Circular A-4 (2003) recognizes that special considerations arise when applying discount rates if intergenerational effects are important. In the IWG's 2015 *Response to Comments*, OMB—as a co-chair of the IWG—made clear that “Circular A-4 is a living document,” that “the use of 7% is not considered appropriate for intergenerational discounting,” and that “[t]here is wide support for this view in the academic literature, and it is recognized in Circular A-4 itself.” OMB, as part of the IWG, similarly repeatedly confirmed that “a focus on global SCC estimates in [regulatory impact analyses] is appropriate” (IWG 2015). See Sections 1.3 and 2.3 for further discussion on both issues. In 2023, OMB revised Circular A-4, after the publication of the draft version of this report. Circular A-4 (2023) likewise recognizes that special considerations arise when applying discount rates intergenerationally, including that uncertainty in the future path of the discount rate suggest a focus on lower rates.



To ensure that the methodological updates adopted in this report are consistent with economic theory and reflect the latest science, the EPA initiated an external peer review panel to conduct a high-quality technical review, completed in May 2023. The peer reviewers commended the agency on its development of this update, calling it a much-needed improvement in estimating the SC-GHG and a significant step towards addressing the National Academies' recommendations with defensible modeling choices based on current science.<sup>15</sup> The peer reviewers provided numerous recommendations for refining the presentation and for future modeling improvements, especially with respect to climate change impacts, feedbacks, and associated damages that are not currently included in the analysis. Additional discussion of omitted impacts and other updates have been incorporated to address peer reviewer recommendations. Complete information about the external peer review, including the peer reviewer selection process, the final report with individual recommendations from peer reviewers, and the EPA's response to each recommendation is available at: <https://www.epa.gov/environmental-economics/scghg-tsd-peer-review>.<sup>16</sup>

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<sup>15</sup> Examples of supportive statements from each of the seven peer reviewers included:

- The report *"represents a huge advance in estimating the US Social Cost of Carbon (SCC). The estimates reported have successfully incorporated all of the short-term recommendations of the National Research Council (NRC) Committee on Valuing Climate Damages, and some of the longer-term recommendations. The report represents the state-of-the-art in executing the four steps of SCC calculation: (1) calculating probability distributions over future paths of population, GDP and emissions; (2) translating future emissions into future climate impacts; (3) estimating net damages associated with changes in climate; (4) discounting future damages to the present."*
- *"The approach taken to generate SC-GHG estimates is well-designed and executed and the document is well-written and easy to follow, although missing key details (as I describe below in my detailed comments)."*
- *"The update...is a significant step towards addressing the National Academies report in 2017 and continuing to improve the ability to assess the impact on the United States."*
- The document *"provides the basis for both an improved estimate to be used in rulemaking in the near term, as well as providing the core foundation for continuing refinements and improvements in the future....The overall structure of the report is clear and the development of the modular approach as recommended by NASEM is well articulated. By establishing a modular platform, the Agency is well positioned to both improve the current set of estimates and allow for updates over time as the scientific and economic basis for the estimates evolve and improve."*
- *"The document...is, as far as this reader can discern, accurate in its representation of the current literature. The presentation is exceptionally clear and would be accessible to a knowledgeable non-expert working in the climate policy domain. The document's conclusions are sound within the self-constrained scope of its analysis."*
- *"It should be noted that several [public] comments were very complimentary for the work EPA had conducted...I concur – EPA is advancing our state of knowledge. There are specific suggestions for improvements I will discuss in more detail below, but I believe the proposed rule is an important step forward."*
- The Report *"represents a real step change in the formal calculation of the U.S. Social Cost of Carbon (SC-CO<sub>2</sub>), not least because of its explicit calculation of the Social Cost of Methane (SC-CH<sub>4</sub>) and Nitrous Oxide (SC-N<sub>2</sub>O). It is generally well-written, technically sound, responsive to a host of comments and inputs (e.g., National Academy of Sciences 2017; Carleton and Greenstone 2021; Wagner et al. 2021) since the prior updates under the Obama administration...and generally represents well the emerging consensus in the literature (e.g., Moore et al. 2023)."*

<sup>16</sup> In addition, the EPA solicited public comment on the use of the updated SC-GHG estimates and the external review draft of this report in the docket for EPA's December 2022 Supplemental Notice of Proposed Rulemaking, "Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector Climate Review." All the public comments and EPA's responses to the comments are available in the rule docket at: <https://www.regulations.gov/docket/EPA-HQ-OAR-2021-0317>.

## 1.2 Recommendations from the National Academies of Sciences, Engineering, and Medicine

As previously mentioned, in 2015, the IWG requested that the National Academies review and recommend potential approaches for improving its SC-CO<sub>2</sub> estimation methodology. In response, the National Academies convened a multidisciplinary committee, called the Committee on Assessing Approaches to Updating the Social Cost of Carbon. In addition to evaluating the IWG's overall approach to SC-CO<sub>2</sub> estimation, the committee reviewed its choices of IAMs and damage functions, climate science assumptions, future baseline socioeconomic and emission projections, presentation of uncertainty, and discount rates.

In its final report (National Academies 2017), the National Academies committee recommended that the IWG pursue an integrated modular approach to the key components of SC-CO<sub>2</sub> estimation to allow for independent updating and review and to draw more readily on expertise from the wide range of scientific disciplines relevant to SC-CO<sub>2</sub> estimation. Under this approach, each step in SC-CO<sub>2</sub> estimation is developed as a module—socioeconomic projections, climate science, economic damages, and discounting—that reflects the state of scientific knowledge in the current peer-reviewed literature. In the longer term, it recommended that the IWG communicate research needs and priorities to its member agencies to stimulate research on ways to improve accounting of interactions and feedbacks between these components. In addition, the committee noted that, while the IWG harmonized key inputs across three IAMs, shifting to the use of a single climate module in the nearer-term (2-3 years) and eventually transitioning to a single framework for all modules will enhance transparency, improve consistency with the underlying science, and allow for more explicit representation of uncertainty. It recommended these three criteria also be used to judge the value of other updates to the methodology. It also recommended that the IWG update SC-CO<sub>2</sub> estimates at regular intervals, suggesting a five-year cycle.

Regarding the key components of the SC-CO<sub>2</sub>, the committee recommended the following improvements:

***Socioeconomic and emissions projections:*** Use accepted statistical methods and elicit expert judgment to project probability distributions of future annual growth rates of per-capita gross domestic product (GDP) and population, bearing in mind the potential correlation between economic and population projections. Use expert elicitation, guided by information on historical trends and emissions consistent with different climate outcomes, to project emissions for each forcing agent of interest, conditional on population and income scenarios. Additional recommendations were offered pertaining to the time horizon, inclusion of future policies, disaggregation of scenarios, and feedbacks from the damage module to the socioeconomic module.

***Climate science:*** Adopt or develop a simple Earth system model (such as the Finite Amplitude Impulse Response (FaIR) model) to capture the relationships between CO<sub>2</sub> emissions, atmospheric CO<sub>2</sub> concentrations, and global mean surface temperature change over time while accounting for non-CO<sub>2</sub> forcing and allowing for the evaluation of uncertainty. Adopt or develop a sea level rise component in the climate module that: (1) accounts for uncertainty in the translation of global mean temperature to global mean sea level rise and (2) is consistent with sea level rise projections available in the literature for similar forcing and temperature pathways. The committee also

noted the importance of generating spatially and temporally disaggregated climate information as inputs into damage estimation. It recommended the use of linear pattern scaling (which estimates linear relationships between global mean temperature and local climate variables) to achieve this goal in the near-term.

***Economic damages:*** Improve and update existing formulations of individual sectoral damage functions as feasible; characterize damage function calibrations quantitatively and transparently; present a summary of disaggregated (incremental and total) damage projections and discuss how they scale with temperature, income, and population; and recognize any correlations between formulations when multiple damage functions are used.

***Discounting:*** Account for the relationship between economic growth and discounting; explicitly recognize uncertainty surrounding discount rates over long time horizons using a Ramsey-like approach; select parameters to implement this approach that are consistent with theory and evidence to produce certainty-equivalent discount rates consistent with near-term consumption rates of interest; use three sets of Ramsey parameters to generate a low, central, and high certainty-equivalent near-term discount rate, and three means and ranges of SC-CO<sub>2</sub> estimates; discuss how the SC-CO<sub>2</sub> estimates should be combined with other cost and benefit estimates that may use different discount rates in regulatory analysis.

Additional details on the National Academies' near-term recommendations are provided in Section 2 below. The National Academies' final report also provided longer-term recommendations pertaining to each module and identified research priorities for addressing these recommendations.

In focusing on the four categories above, the National Academies left various topics for future research. For example, the report pointed to future research that might enable more robust methods of capturing the benefits of reducing climate risks. While the National Academies report did not explicitly address methods to account for the disproportionate climate damages that may accrue to lower-income individuals in SC-GHG estimates, it did outline ways to present evidence on the possible distributional effects of climate change. The National Academies point to the importance of presenting spatially disaggregated results that could, in turn, enable methods that would better identify vulnerable populations and those most at risk. Additional discussion of these dimensions can be found in Section 3.3 of this report.

### **1.3 Accounting for Global Damages**

Benefit-cost analyses of U.S. Federal regulations have traditionally focused on the benefits and costs that accrue to individuals that reside within the country's national boundaries and that accrue to regulated industries, regardless of the nationality of the owners of affected physical assets.<sup>17</sup> This approach reflects the fact that for most regulations, those are the two groups primarily affected. It does not reflect any other scientific, legal, or other rationale. The default recommendation in OMB's Circular A-4 (2003) is that, an "analysis should focus on benefits and costs that accrue to citizens and residents of the United

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<sup>17</sup> It is customary in the benefit-cost analyses of U.S. Federal regulations to include the full compliance costs that accrue to entities operating in the U.S., even if those costs are fully or partially borne by owners, employees, or consumers that reside outside of the U.S.

States.”<sup>18</sup> However, OMB Circular A-4 (2003) states that when a regulation is likely to have international effects, “these effects should be reported”; and though the guidance recommends this be done separately, the guidance also explains that “[d]ifferent regulations may call for different emphases in the analysis, depending on the nature and complexity of the regulatory issues.”<sup>19</sup> The National Academies advised that “[i]t is important to consider what constitutes a domestic impact in the case of a global pollutant that could have international implications that affect the United States” (National Academies 2017, p. 13). There are many reasons, as summarized in this section – and as articulated by OMB and in IWG assessments (IWG 2010, 2013, 2016a, 2016b, 2021) and the 2015 Response to Comments (IWG 2015) – why the EPA uses the global value of climate change impacts when analyzing policies that affect GHG emissions. Courts have upheld the use of global estimates of the SC-GHG, partially in recognition of the diverse ways in which U.S. interests, businesses, and residents are impacted by global climate change.<sup>20</sup>

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<sup>18</sup> OMB’s Circular A-4 (2003) provides guidance to Federal agencies on the development of regulatory analysis conducted pursuant to Executive Order (E.O.) 12866. Circular A-4 (2023) notes similarly that “In many circumstances, your primary analysis should focus on the effects of a regulation that are experienced by citizens and residents of the United States (which will often be the primary effects of the regulation)” (OMB 2023).

<sup>19</sup> Circular A-4 (2003) also explains “You will find that you cannot conduct a good regulatory analysis according to a formula. Conducting high-quality analysis requires competent professional judgement.” For example, as noted above, benefit-cost analyses have historically often included compliance costs that are ultimately borne by owners, employees, or customers that reside outside of the U.S. It may therefore also be relevant that Circular A-4 generally recommends consistency in the analytical treatment of costs and benefits. (“The same standards of information and analysis quality that apply to direct benefits and costs should be applied to ancillary benefits and countervailing risks” (OMB 2003).) Circular A-4 (2023) states that “In certain contexts, it may be particularly appropriate to include effects experienced by noncitizens residing abroad in your primary analysis. Such contexts include, for example, when:

- assessing effects on noncitizens residing abroad provides a useful proxy for effects on U.S. citizens and residents that are difficult to otherwise estimate;
- assessing effects on noncitizens residing abroad provides a useful proxy for effects on U.S. national interests that are not otherwise fully captured by effects experienced by particular U.S. citizens and residents (e.g., national security interests, diplomatic interests, etc.);
- regulating an externality on the basis of its global effects supports a cooperative international approach to the regulation of the externality by potentially inducing other countries to follow suit or maintain existing efforts; or
- international or domestic legal obligations require or support a global calculation of regulatory effects”

(OMB 2023). As noted in Circular A-4 (2023), “OMB determined in 2021, in its role as a co-chair of the Interagency Working Group on the Social Cost of Greenhouse Gases (IWG), that the effects of changes in greenhouse gas emissions experienced by U.S. citizens and residents could not be separated from the global effects of changes in greenhouse gas emissions in a practical or reasonably accurate manner. At the time, OMB and the IWG noted available models could produce only an unreasonably incomplete underestimate of damages accruing to U.S. citizens and residents. OMB and the IWG recommended use of the IWG’s global estimates of damages because—among other reasons—regulating greenhouse gas emissions on the basis of their global effects supports a cooperative international approach to the regulation of greenhouse gas emissions by potentially inducing other countries to follow suit or maintain existing efforts, and the global estimates were a useful proxy for effects on U.S. citizens and residents that were difficult to estimate and for effects on U.S. national interests that were not otherwise fully captured” (OMB 2023).

<sup>20</sup> *Zero Zone, Inc. v. Dep’t of Energy*, 832 F.3d 654, 678-79 (7th Cir. 2016) (rejecting a petitioner’s challenge to DOE’s use of a global social cost of carbon in setting an efficiency standard under the Energy Policy and Conservation Act,

Unlike many environmental problems where the causes and impacts are distributed more locally, GHG emissions are a global externality making climate change a true global challenge. GHG emissions contribute to damages around the world regardless of where they are emitted. The global nature of GHG pollution and its impacts means that U.S. interests are affected by climate change impacts through a multitude of pathways, and these need to be considered when evaluating the benefits of GHG mitigation to the U.S. population. For example, climate change will directly impact U.S. interests that are located abroad (such as U.S. citizens, investments, military bases and other assets, and resources in the global commons (e.g., through changes in fisheries' productivity and location)). An estimated 9 million U.S. citizens lived abroad as of 2020 (DOS 2020), and the U.S. direct investment abroad position totaled \$6.15 trillion at the end of 2020 (BEA 2021). U.S. taxpayers report a substantial amount of income coming from foreign sources,<sup>21</sup> and nearly 40% of U.S. pension assets' equity holdings are in foreign stocks (TAI 2022). Climate impacts occurring outside of U.S. borders have a direct impact on these U.S. citizens and the investment returns on those assets owned by U.S. citizens and residents. In addition, the U.S. has over 500 military sites abroad across 45 foreign countries (see Figure 1 in DoD 2018). Climate change impacts (such as sea level rise) occurring in these locations already affect U.S. military infrastructure and will continue to lead to increased expenditures to maintain bases' viability and readiness (USGCRP 2018a). Failure to do so can lead to impacts on mission execution and increased security risks. As one example, "...the United States has important defense assets located in...the Marshall Islands, and Palau, all of which are vulnerable to these [climate] hazards. Additionally, competitors such as China may try to take advantage of climate change impacts to gain influence" (DoD 2021). The timing and severity of climate events are already affecting missions in some cases and these risks are expected to increase. For example, in the Marshall Islands, the Ronald Reagan Ballistic Missile Defense Test Site, "a pillar of U.S. Strategic Command" used for detecting foreign missile launches, may be "uninhabitable in mere decades" according to a recent study conducted by the Center for Climate and Security's Military Expert Panel (CCS 2018).

The U.S. economy is also inextricably linked to the rest of the world. The U.S. exports over \$2 trillion worth of goods and services a year and imports around \$3 trillion (BEA 2023a). According to recent data, over 20% of American firms' profits are earned on activities outside the country (BEA 2023c). Climate impacts that occur outside U.S. borders will impact the welfare of individuals and the profits of firms that reside in the U.S. because of their connection to the global economy. This will occur through the effect of climate change on international markets, trade, tourism, and other activities. Supply chain disruptions are a prominent pathway through which U.S. business and consumers are, and will continue to be, affected by climate change impacts abroad. The impact of international supply chain disruptions can be severe. For example, severe flooding in Thailand in 2011 disrupted production of components for global companies including computer disk drives and cars (USGCRP 2018a, DoD 2021). As a result, U.S. consumers faced higher prices for many electronic goods. The U.S.-based firm Western Digital alone posted \$199 million in losses and a 51% drop in hard drive shipments, and U.S. vehicle production had to be temporarily halted

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holding that DOE had reasonably identified carbon pollution as "a global externality" and concluding that, because "national energy conservation has global effects, . . . those global effects are an appropriate consideration when looking at a national policy.").

<sup>21</sup> For example, in 2016, approximately \$216.7 billion, or 2.1% of total worldwide income for all U.S. taxpayers, were reported to come from foreign sources (IRS 2016). For 2018, over 9,800 corporations reported almost \$768 billion of foreign-source taxable income (IRS 2018).

or reduced considerably by at least two manufacturers (USGCRP 2018a). As climate change increases the severity and frequency of extreme weather events, it increases the risk of supply chain disruptions. Recent research finds the “probability of a hurricane of sufficient intensity to disrupt semiconductor supply chains may grow two to four times by 2040” and the “probability heavy rare earth [metals] production is severely disrupted from extreme rainfall may increase 2 to 3 times by 2030” (Woetzel et al. 2020).

Additional climate change-induced international spillovers can occur through pathways such as damages across transboundary resources, economic and political destabilization, and global migration that can lead to adverse impacts on U.S. national security, public health, and humanitarian concerns (DoD 2014, CCS 2018). Numerous studies have called attention to how stressors leading to these spillovers are already occurring and are expected to worsen with increasing climate change. For example, the United Nations High Commissioner for Refugees (UNHCR) reports that an average of 21.5 million people were forcibly displaced each year by sudden onset weather-related hazards between 2008 and 2016, and thousands more from slow-onset hazards linked to climate change impacts (UNHCR 2016). As articulated in a landmark 2007 study by retired three- and four-star Generals and Admirals - and echoed in the Department of Defense’s (DoD) 2014 Quadrennial Defense Review – the projected effects of climate change act as a “threat multiplier” that will exacerbate many stressors and instabilities that already exist in some of the most volatile regions of the world (CNA 2007, DoD 2014). A follow-up study emphasized that beyond being a threat multiplier, climate change impacts will also “serve as catalysts for instability and conflict” (CNA 2014). For example, in Sub-Saharan Africa regional environmental stressors exacerbated by climate change can help to transform resource competition into ethno-political conflict and enable the involvement of transnational terrorist groups (such as Al Qaeda in the Islamic Maghreb (AQIM) in Mali in 2012) (CNA 2014). More recent DoD reports reiterate these concerns, concluding that the impacts of climate change “could stress economic and social conditions that contribute to mass migration events or political crises, civil unrest, shifts in the regional balance of power, or even state failure,” with results that affect the national interests of the U.S. (DoD 2021). The key takeaway from the National Intelligence Council’s (NIC) 2021 National Intelligence Estimate is that “climate change will increasingly exacerbate risks to US national security interests as the physical impacts increase and geopolitical tensions mount about how to respond to the challenge” (NIC 2021). The NIC finds “the increasing physical effects of climate change are likely to exacerbate cross-border geopolitical flashpoints as states take steps to secure their interests”, and as intensifying physical effects “out to 2040 and beyond will be most acutely felt in developing countries, which we assess are also the least able to adapt to such changes...[t]hese physical effects will increase the potential for instability and possibly internal conflict in these countries, in some cases creating additional demands on US diplomatic, economic, humanitarian, and military resources” (NIC 2021).

As described by the National Academies (2017), to correctly assess the total damages to U.S. citizens and residents, one must account for these spillover effects on the U.S. For more discussion and examples of international spillover effects, including the ways that climate change spillovers are exacerbating existing risks and creating new security, health, and humanitarian challenges for U.S. interests, see for example, NIC (2021), DoD (2021), USGCRP (2018a), Freeman and Guzman (2009), Howard and Livermore (2021), Schwartz (2021), and IPCC (2022).

The global models used in SC-GHG estimation do not lend themselves to disaggregation in a way that can provide a comprehensive estimate of climate change damages to U.S. citizens and residents that accounts

for the myriad of ways that global climate change reduces the net welfare of U.S. populations. At present, the only quantitative characterizations of U.S. damages from GHG emissions are based on the share of modeled damages that physically occur within U.S. national borders as represented in current IAMs. Such estimates provide an underestimate of the climate change damages to the citizens and residents of the U.S. because these models do not fully capture the range of climate change impacts and exclude important regional interactions and spillovers discussed above. In addition, a 2020 GAO study observed that “[a]ccording to the National Academies, the integrated assessment models were not premised or calibrated to provide estimates of the social cost of carbon based on domestic damages, and more research would be required to update the models to do so” (GAO 2020). Further, the National Academies observed that existing models “focus primarily on global estimates and do not model all relevant interactions among regions....More thoroughly estimating a domestic SC-CO<sub>2</sub> would therefore need to consider the potential implications of climate impacts on, and actions by, other countries, which also have impacts on the United States” (National Academies 2017, p. 13).

In addition to accounting for the ways that climate change impacts occurring outside of U.S. borders affect U.S. populations, it is also important to consider how changes in U.S. emissions affect the GHG emissions of other countries. This is relevant because the global nature of greenhouse gases means that a ton of GHGs emitted in any other country harms those in the U.S. just as much as a ton emitted within the territorial U.S. This is a classic public goods problem because each country’s reductions benefit everyone else, and no country can be excluded from enjoying the benefits of other countries’ reductions. As discussed by EPA and other members of the IWG in the 2015 response to comments (IWG 2015), in this situation, the only way to achieve an efficient allocation of resources for emissions reduction on a global basis—and so benefit the U.S. and its citizens and residents—is for all countries to consider estimates of global marginal damages. If each country were to design policies to equate marginal damages with marginal abatement costs using only the damages inflicted by that country on their own citizens and residents, the world would not achieve the socially optimal level of emissions; each country would be relatively worse off from the impact of foreign emissions.<sup>22</sup> In addition, international GHG mitigation activities taken in response to U.S. policies that reduce emissions will also provide a benefit to U.S. citizens and residents. It is, therefore, consistent with best analytical practices to account for the global marginal damages of GHG emissions given their role as a global externality.

Several studies have examined the evidence on international GHG mitigation reciprocity, through both policy diffusion and technology diffusion effects. For example, using panel data on national and subnational carbon pricing policies in place over 1988 to 2021, Linsenmeier et al. (2023) estimate that the adoption of carbon pricing policies in one country increases the probability of carbon pricing adoption in other countries. Based on their empirical results, they find that the indirect GHG emissions reductions attributable to international reciprocity may exceed domestic emission reductions from the policy. In another recent study, Larsen et al. (2023) investigate how U.S. climate policy can lead to reductions in the cost of GHG mitigation technologies globally and thus resulting in foreign emissions reductions. Larsen et

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<sup>22</sup> As Morgenstern et al. (2023) explain: “...US greenhouse gas emissions account for about 12 percent of the global total. If all countries considered only the domestic effects of their greenhouse gas emissions, about 88 percent of climate change impacts on US citizens would be ignored. An analytic focus solely on direct impacts to the United States of US emissions, when generalized, therefore omits most of the total climate impacts the United States faces” (Morgenstern et al. 2023, p. 5).



al. (2023) refer to this as technology diffusion effects and they are expected to occur independent of reciprocal policy adoption in other countries. Focusing on the tax incentives for three key emerging climate technologies in the Inflation Reduction Act, they estimate that in the long run the incentives will reduce 2.4 to 2.9 tons of GHGs outside the U.S. for every ton reduced within the U.S. In addition, Houser et al. (2023) present a new analysis quantifying the extent to which other countries have made GHG emission reduction commitments and progressed towards meeting those commitments alongside the U.S. under 2015 Paris Agreement.<sup>23</sup> The authors highlight how the agreed structure of the process – for countries to develop and communicate their “intended nationally determined contributions” (INDCs) “well in advance” of the Paris conference (UNFCCC 2014) - provided time for countries “to assess whether there was sufficient reciprocal action to justify their own intended emission reduction pledge” (Houser et al. 2023). One result of this format was that the U.S. and China ended up jointly announcing their INDCs, after nine months of bilateral negotiations (Lander 2014), stating “The United States and China hope that by announcing these targets now, they can inject momentum into the global climate negotiations and inspire other countries to join in coming forward with ambitious actions as soon as possible” (The White House, 2014). By the start of the Paris conference, 151 countries had announced INDCs (UNFCCC 2023), with emission reduction commitments almost evenly distributed among developed and developing countries (Houser et al. 2023). By comparing countries’ submitted emission reduction commitments and plans (NDCs) over time to an independent Pre-Paris Agreement emissions projection baseline, Houser et al. (2023) calculate a ratio of the rest of the world’s committed reductions to the U.S.’ committed reduction, or “Climate Reciprocity Ratio” (CRR). They estimate CRRs ranging from 2.4 to 10.8. The authors note that the upper end of the range applies to the middle of the century when the U.S. share of global emissions has declined. Relatedly, Schmidt et al. (2022) find that the free-rider hypothesis cannot be supported in the context of climate policy. Using data on emission-weighted carbon prices, while controlling for a variety of other potential explanatory variables, the authors find that the evidence does not support the presence of free riding.

A wide range of scientific and economic experts have emphasized the issue of international cooperation and reciprocity as support for assessing global damages of GHG emissions in domestic policy analysis (e.g., Kopp and Mignone 2013, Pizer et al. 2014, Howard and Schwartz 2017, Pindyck 2017, 2021, Revesz et al. 2017, Carleton and Greenstone 2022, Houser et al. 2023). Kotchen (2018) demonstrates how a country’s decision to internalize global damages in domestic policymaking can be individually rational (i.e., in the country’s own self-interest) because of the reciprocally induced emissions reductions occurring in other countries.<sup>24</sup> Carleton and Greenstone (2022) discuss examples of how accounting for global damages in past U.S. regulatory analyses may have contributed to additional international action.

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<sup>23</sup> Houser et al. (2023) is an update and expansion of an assessment of cumulative emissions reduction pledges under the Paris Agreement by Houser and Larsen 2021.

<sup>24</sup> Kotchen (2018) not only details the “efficiency argument in support of all countries internalizing the GSCC [global social cost of carbon] for domestic policy,” but Kotchen (2018) also introduces the concept of countries having a “preferred” social cost of carbon (PSCC) for setting global climate policy and shows that all countries’ PSCC exceeds the marginal damages to its own populations. The PSCC is shaped by a country’s expected benefits from other countries’ emission reductions. Kotchen’s study shows that in some countries the PSCC can even exceed the value of global marginal damages (e.g., in small island nations for whom the benefits of stringent worldwide abatement based on a high PSCC would exceed the increase in its own abatement costs due to a high PSCC). Kotchen offers

Assessing global marginal damages of GHG emissions in U.S. analyses of regulatory and other actions allows the U.S. to continue to actively encourage other nations, including emerging economies, to also assess global climate damages of their policies and to take steps to reduce emissions. Many countries and international institutions have either already explicitly adapted the IWG's estimates of global damages in their domestic analyses (e.g., Canada<sup>25</sup>, Israel<sup>26</sup>), developed their own estimates of global damages (e.g., Germany<sup>27</sup>), or have taken note of the IWG estimates in their assessments of climate policies (e.g., Japan,<sup>28</sup> Trinidad and Tobago,<sup>29</sup> Australia<sup>30</sup>, India's National Green Tribunal<sup>31</sup>, Italy<sup>32</sup>, New Zealand<sup>33</sup>, and the International Monetary Fund<sup>34</sup>). In 2016, Mexico announced its intention to "align approaches [with the U.S. and Canada] to account for the social cost of carbon and other greenhouse gas emissions when assessing the benefits of emissions-reducing policy measures"<sup>35</sup>, and references to global estimates of climate damages can be found in Mexican regulatory analyses in 2017.<sup>36</sup> However, the bilateral technical discussions to help implement the announced plan did not occur over 2017-2021 during the time U.S. federal regulatory analyses stopped focusing on SC-GHG estimates that reflect global damages.

Recently, there has been renewed interest by other countries to update their estimates since the draft release of the updated estimates presented in this report. In January 2023, at the North American Leaders Summit, the United States, Canada, and Mexico reaffirmed their commitment to "come together to align approaches on estimating the social cost of greenhouse gas emissions" (CEC 2023). Since then, Mexico has re-engaged in discussions regarding SC-GHG estimation. In April 2023, the government of Canada announced the publication of an interim update to their SC-GHG guidance, recommending SC-GHG estimates identical to the EPA's updated estimates presented in this report (ECCC 2023). The Canadian

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illustrative estimates of the PSCC for several countries and regions based on research using a regionalized version of the DICE model (Nordhaus 2015). In this analysis Kotchen finds the U.S. PSCC to be nearly 75% of the value of global marginal damages. And as Kotchen has further clarified, "depending on the U.S. government's diplomatic strategies, its expectations of international reciprocity, and the international distribution of costs, it can be rational for the United States to adopt the full global SCC values for use in policy-making" (Kotchen 2021, comment number OMB-2021-0006-0018, available at: <https://www.regulations.gov/comment/OMB-2021-0006-0018>). Such arguments for accounting for the global value of climate change impacts in analysis of policies affecting U.S. GHG emissions, based on the U.S. derived benefits from reciprocally induced emission reductions elsewhere, are distinct from and additional to arguments above based on spillover effects and U.S. interests beyond our geographic borders.

<sup>25</sup> See ECCC (2016).

<sup>26</sup> See Israel Ministry of Environmental Protection (2020)

<sup>27</sup> See GAO (2020) for a discussion of Germany's SC-GHG values; see also UBA (2020, 2021).

<sup>28</sup> Japan's Ministry of Internal Affairs and Communications explains in its reference manual for regulatory policy evaluations that Japan has no official value for the social cost of carbon but cites the IWG values as a reference. See MIC (2017, 2021).

<sup>29</sup> Trinidad and Tobago used the IWG values in their 2021 Third National Communication to the United Nations Framework Convention on Climate Change (Ministry of Planning and Development 2021).

<sup>30</sup> See, for example, ACT (2019) and Hutley (2021).

<sup>31</sup> See Patel et al. (2020).

<sup>32</sup> A research institute established by the Italian government uses the IWG estimates. See ISPRA (2016a, 2016b).

<sup>33</sup> See Ministry of Transport (2018).

<sup>34</sup> See Clements et al. (2013).

<sup>35</sup> See White House (2016) for a joint statement from Canada, the U.S., and Mexico.

<sup>36</sup> See Secretaria del Medio Ambiente y Recursos Naturals (2016).

interim guidance will be used across all federal departments and agencies, with the values expected to be finalized by the end of the year.

EPA and other members of the IWG found previously and restated in their February 2021 TSD that because of the distinctive global nature of climate change that analysis of Federal regulations and other actions should center on a global measure of SC-GHG (IWG 2021). This is the same approach that was recommended by OMB and other members of the IWG and used by EPA and other agencies in regulatory analyses from 2009 to 2016. It is also consistent with guidance in OMB Circular A-4 (2003) that “[d]ifferent regulations may call for different emphases in the analysis, depending on the nature and complexity of the regulatory issues,”<sup>37</sup> and National Academies’ guidance that “it is important to consider what constitutes a domestic impact in the case of a global pollutant that could have international implications that impact the United States.” In the case of this global pollutant, for all the reasons articulated in this section, the assessment of global net damages of GHG emissions allows analysts to fully disclose and contextualize the net climate benefits of domestic policies that reduce GHG emissions. The extent that analysis relying on these SC-GHG estimates is considered in setting the stringency of future regulatory actions and other policy decisions would be guided by the statutes under which those decisions are promulgated.<sup>38,39</sup> The EPA will continue to review developments in the literature, including more robust methodologies for estimating the magnitude of the various direct and indirect damages to U.S. populations from climate impacts occurring abroad and reciprocal international mitigation activities.

## 2 Methodological Updates

The SC-GHG is commonly estimated with the use of integrated assessment models (IAM). In the broadest sense IAMs are “approaches that integrate knowledge from two or more domains into a single framework” (Nordhaus 2018a). The literature on “IAMs” is vast and spans many scientific disciplines, e.g., Earth sciences, biological sciences, environmental engineering, economics, and sociology. IAMs have been used to study environmental problems and their connection to economic systems for nearly 40 years (e.g., Freeman 1979, 1982; Mendelsohn 1980; Nordhaus 1993a, 1993b). The National Academies defined IAMs used to study climate change as “computational models of global climate change that include representation of the global economy and greenhouse gas emissions, the response of the climate system

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<sup>37</sup> The same guidance is in OMB Circular A-4 (2023).

<sup>38</sup> For example, as the Supreme Court stated in *Motor Vehicle Manufacturers Ass’n. v. State Farm Mutual Auto. Ins. Co.*, 463 U.S. 29, 41-43 (1983): “Normally, an agency rule would be arbitrary and capricious if the agency has relied on factors which Congress has not intended it to consider, entirely failed to consider an important aspect of the problem, offered an explanation for its decision that runs counter to the evidence before the agency, or is so implausible that it could not be ascribed to a difference in view of the product of agency expertise.” This requires agencies to “examine the relevant data and articulate . . . a rational connection between the facts found and the choice made.”

<sup>39</sup> Public comments received on the February 2021 TSD argue that key U.S. statutes explicitly require or allow consideration of global climate damages in decision making. See, e.g., the discussion within comments submitted by the Institute for Policy Integrity and the attachments and literature cited therein (Institute for Policy Integrity 2021). The comments discuss, for example, how the National Environmental Policy Act requires that “public laws of the United States shall be interpreted and administered in accordance with the policies set forth in this chapter, and all agencies of the Federal Government shall...recognize the worldwide and long-range character of environmental problems”.

to human intervention, and impacts of climate change on the human system” (National Academies 2017). These IAMs vary significantly in structure, geographic resolution, the degree to which they capture feedbacks within and between natural and economic systems and include valuation, and application. Those that are used to estimate the SC-GHG are reduced-form in nature and combine climate processes, economic growth, and feedback between the climate and the global economy into a single modeling framework, providing a holistic view of the system, and include a valuation of climate change damages. Other climate change IAMs, often called detailed-structure IAMs, include structural representations of the global economy with a high level of regional and sectoral detail, and were originally developed for analyzing the impact of policy and technology on greenhouse gas emissions (e.g., Edmonds and Reilly, 1983). These types of IAMs are increasingly being used to examine different climate change impact sectors and interactions between sectors and regions but do not yet comprehensively link physical impacts to monetized economic damages as needed for SC-GHG estimation (National Academies 2017).

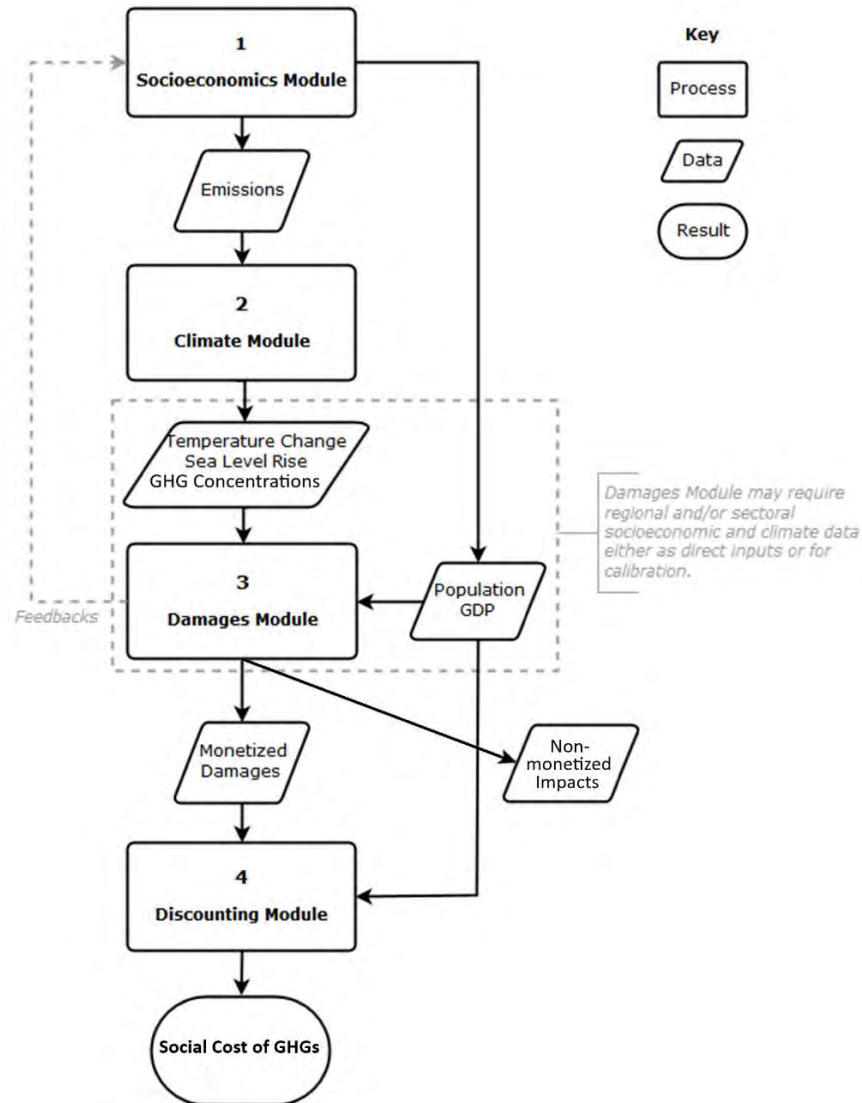
As illustrated in Figure 2.1, and as mentioned above, the steps necessary to estimate the SC-GHG with a climate change IAM can generally be grouped into four modules: socioeconomics and emissions, climate, damages, and discounting. The emissions trajectories from the socioeconomic module are used to project future temperatures in the climate module. The damage module then translates the temperature and other climate endpoints (along with the projections of socioeconomic variables) into physical impacts and associated monetized economic damages, where the damages are calculated as the amount of money the individuals experiencing the climate change impacts would be willing to pay to avoid them. To calculate the marginal effect of emissions, i.e., the SC-GHG in year  $t$ , the entire model is run twice – first as a baseline and second with an additional pulse of emissions in year  $t$ . After recalculating the temperature effects and damages expected in all years beyond  $t$  resulting from the adjusted path of emissions, the losses are discounted to a present value in the discounting module. Much of the uncertainty in the models can be incorporated using Monte Carlo techniques by taking draws from probability distributions that reflect the uncertainty in parameters.

The SC-GHG estimates used by the EPA and many other federal agencies since 2009 have relied on an ensemble of three widely used IAMs: Dynamic Integrated Climate and Economy (DICE) (Nordhaus 2010); Climate Framework for Uncertainty, Negotiation, and Distribution (FUND) (Anthoff and Tol 2013a, 2013b); and Policy Analysis of the Greenhouse Gas Effect (PAGE) (Hope 2013). In 2010, the IWG harmonized key inputs across the IAMs, but all other model features were left unchanged, relying on the model developers’ best estimates and judgments. That is, the representation of climate dynamics and damage functions included in the default version of each IAM as used in the published literature was retained.

The SC-GHG estimates in this report no longer rely on the three IAMs (i.e., DICE, FUND, and PAGE) used in previous SC-GHG estimates. Instead, this report uses a modular approach to estimating the SC-GHG, consistent with the National Academies’ near-term recommendations. That is, the methodology underlying each component, or module, of the SC-GHG estimation process draws on expertise from the scientific disciplines relevant to that component. Under this approach, each step in the SC-GHG estimation improves consistency with the current state of scientific knowledge, enhances transparency, and allows for more explicit representation of uncertainty. This section discusses the methodological updates in each of the four National Academies’ recommended modules in addition to other updates in the modeling framework, such as the explicit incorporation of risk aversion. The discussion is intended to provide an

overview of the methods used in each module. Additional details of each underlying study are available in the sources cited throughout the report.

Figure 2.1: The Four Components of SC-GHG Estimation



Source: Adapted from National Academies of Sciences, Engineering, and Medicine (2017)

## 2.1 Socioeconomic and Emissions Module

The first step in the SC-GHG estimation process is the development of projections of socioeconomic variables and GHG emissions at the spatial and temporal resolution required by the climate and damage modules. Socioeconomic trajectories are closely tied to climate damages because, holding all else equal,

increases in population and income<sup>40</sup> will increase GHG emissions and lead to a greater willingness to pay to avoid climate change impacts. Within the SC-GHG estimation process, projections of GHG emissions serve as inputs to the climate module, and projections of GDP and population serve as inputs to the damage function and discounting modules. Disaggregation of these inputs is required when greater spatial and/or temporal resolution is required for the damage module. Finally, because GHG emissions and their effects are long lived, it is necessary to project these variables far into the future and address the many complex uncertainties associated with such projections.

SC-GHG estimates used in the EPA's analyses to date have relied on the socioeconomic and emissions projections selected by the IWG in 2010. The IWG elected to use socioeconomic and emissions projections based on deterministic scenarios that, at the time, were recently updated, grounded in multiple well-recognized models, used in climate policy simulations, and spanned a plausible range of outcomes for these variables. The socioeconomic and emission projections included five deterministic reference scenarios based on the Stanford Energy Modeling Forum EMF-22 modeling exercise (Clarke et al. 2009; Fawcett, et al. 2009). Four of these scenarios represented business-as-usual (BAU) trajectories, while the fifth scenario assumed that substantive actions would be adopted to reduce future emissions. The SC-GHG estimates gave equal weight to each scenario. The IWG also elected to use a time horizon extending to 2300 to try to capture the vast majority of discounted climate damages. Running the IAMs through 2300 required extrapolations of the projections after 2100, the last year available for projections from the EMF-22 models.<sup>41</sup>

The National Academies 2017 final report included several recommendations for how to approach updating the socioeconomic module to reflect newer information. The National Academies (2017) recommended that socioeconomic scenarios used to estimate the SC-GHG should: "extend far enough in the future to provide inputs for estimation of the vast majority of discounted climate damages"; "take account of the likelihood of future emissions mitigation policies and technological developments"; "provide the sectoral and regional detail in population and GDP necessary for damage calculations"; and, "to the extent possible...incorporate feedbacks from the climate and damages modules that have a significant impact on population, GDP, or emissions" (National Academies, 2017, p. 15). The National Academies acknowledged that it would not be possible to meet all these criteria in the near term. However, the report suggested initial steps for how to achieve these goals and overcome several limitations in the methodology used to date. Specifically, they recommend:

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<sup>40</sup> This report uses gross income and gross production interchangeably. Gross national income (GNI) is gross domestic production (GDP) plus net receipts abroad. For most countries GNI and GDP are similar.

<sup>41</sup> These inputs were extrapolated from 2100 to 2300 as follows: (1) population growth rate declines linearly, reaching zero in the year 2200; (2) GDP/ per capita growth rate declines linearly, reaching zero in the year 2300; (3) the decline in the fossil and industrial carbon intensity (CO<sub>2</sub>/GDP) growth rate over 2090-2100 is maintained from 2100 through 2300; (4) net land use CO<sub>2</sub> emissions decline linearly, reaching zero in the year 2200; and (5) non-CO<sub>2</sub> radiative forcing remains constant after 2100. See IWG (2010) for more discussion of each of these assumptions. In 2016, the IWG added more specificity to the assumptions regarding post-2100 baseline CH<sub>4</sub> and N<sub>2</sub>O emissions in order to calculate SC-CH<sub>4</sub> and SC-N<sub>2</sub>O. See IWG (2016b) for more details.

- (1) working with demographers to extend existing probabilistic population projections beyond 2100, validated and adjusted by expert judgment;
- (2) generating probabilistic projections of annual growth rates of per-capita GDP with an appropriate statistical technique, informed by expert judgment;
- (3) using a set of emissions projections generated by an expert elicitation, conditioned by the set of scenarios of future population and income; and
- (4) developing projections of sectoral and regional GDP and regional population using scenario libraries, published projections, detailed-structure economic models, or other sources.

***Resources for the Future Socioeconomic and Emissions Projections (RFF-SPs).*** Based on a review of available sources of long-run projections for the socioeconomic variables and GHG emissions necessary for damage calculations, the socioeconomic and emissions projections recently developed under the Resources for the Future Social Cost of Carbon Initiative (Rennert et al. 2022a) stand out as being most consistent with the National Academies’ recommendations. These projections (hereafter collectively referred to as the RFF-SPs) are an internally consistent set of probabilistic projections of population, GDP, and GHG emissions (CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O) to 2300. Consistent with the National Academies’ recommendation, the RFF-SPs were developed using a mix of statistical and expert elicitation techniques to capture uncertainty in a single probabilistic approach, taking into account the likelihood of future emissions mitigation policies and technological developments, and provide the level of disaggregation necessary for damage calculations. Unlike other sources of projections, they provide inputs for estimation out to 2300 without further extrapolation assumptions. This is a suitable time horizon consistent with the National Academies’ recommendation and OMB Circular A-4 guidance<sup>42</sup>, since in the modeling conducted for this report 2300 is far enough in the future to capture the majority of discounted climate damages (see discussion in Section 3). Including damages beyond 2300 would increase the estimates of the SC-GHG. As discussed in Section 2.5, the use of the RFF-SPs allows for capturing economic growth uncertainty within a calibrated utility approach to discounting. The RFF-SPs were developed as follows.

The country-level population projections are based on Raftery and Ševčíková’s (2023) extension to the Bayesian methodology that the United Nations (UN) has used since 2015 for population forecasting (UN 2015). The UN population forecasts are rooted in a standard cohort-component method of population projection (CCMPP). The projections rely on the demographic balancing equation. Net changes in a country’s population are equal to births minus deaths plus net migration. Births are forecasted using age-specific fertility rates and a fertility transition. Deaths are forecasted using age-specific death rates based on life expectancy forecasts. Net migration is forecasted using short-term projections (i.e., first few five-year periods) and then are assumed to be constant. Generally, components in a CCMPP are deterministic, but the Bayesian method used by the UN for population forecasting treat the fertility rate and life expectancy as uncertain. Net migration rates follow short-term deterministic forecasts and then are held constant beyond the first few five-year periods.

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<sup>42</sup> Regarding the analytic time horizon for regulatory benefit-cost analysis, OMB Circular A-4 (2003) advises “The ending point should be far enough in the future to encompass all the significant benefits and costs likely to result from the rule” (OMB 2003). OMB Circular A-4 (2023) similarly advises “The ending point for your analysis should be far enough in the future to encompass, to the extent feasible, all the important benefits and costs likely to result from all regulatory alternatives being assessed” (OMB 2023).



Raftery and Ševčíková (2023) combine the United Nations statistical approach with expert review and elicitation to extend the projections to 2300. The projections were extended using the same standard UN approach by setting the end year to 2300 instead of 2100. Given the very long-term nature of these forecasts, the results of the statistical model extension were evaluated by an RFF-sponsored panel of 10 leading demographers. The review panel generally supported the approach taken, with a few recommendations for revision (Rennert et al. 2022a, Raftery and Ševčíková 2023). First, the reviewers found the 95% confidence interval for the global fertility rate in 2300 (1.66-2.23) too narrow because the lower bound was too high. Further elicitation resulted in a recommended lower bound of 1.20. In response, Raftery and Ševčíková (2023) adjusted the total fertility rate by adding a variance component (i.e. a random walk) to broaden uncertainty from 2100 to 2250 to better represent the range of fertility rates from the historic record. This random walk component was chosen so that the 95% confidence interval for the world average total fertility rate from 2250 onwards was 1.20-2.23. Second, the panel recommended replacing the UN approach of deterministic migration with stochastic migration. In response, Raftery and Ševčíková (2023) treated net international migration rates as uncertain, forecasted using an age-adjusted net migration rate, and rebalanced so that global net migration is zero in each time period (Azose, Ševčíková, and Raftery 2016). Third, upper limits on population were adjusted so that upper limits on population density depended on geographic area. This was done in response to expert's concerns that populations were too large for some countries. These three adjustments mostly affected population projections beyond 2100. Population projections out to 2100 agree closely with the UN's projections (see Figure 10 in Raftery and Ševčíková 2023). The small differences are due to the minor methodical differences in net migration described above and country-level mortality due to HIV/AIDS epidemics.

The economic growth projections extend research by Müller et al. (2022), who refined a foundational statistical methodology for generating internally consistent long-term probabilistic growth projections at the country level. Specifically, Müller et al. were the first to extend the approach provided in Müller and Watson (2016) for estimating global economic growth. In the raw data Muller et al. (2022) observed a common growth factor for all OECD countries, economic growth that tends to be correlated over time for groups of countries, wide dispersion in the levels of economic production, and that the relative position of countries exhibits persistence. To incorporate these observations Muller et al. (2022) include distinct sources of uncertain economic growth through a clustered hierarchical structure. The four distinct sources are: (1) a common global growth factor (2) a group-of-countries-specific factor (3) a group-of-groups-specific factor (4) and a growth factor unique to each country. Countries are assigned to a group and group-of-group by the model and it is estimated probabilistically. The groups and groups-of-groups estimated by the model generally align with familiar country groupings (e.g., Australia, Canada, New Zealand, the United States, and the United Kingdom fell into one group). The factors are parametrized to account for the speed of convergence, convergence groups (i.e., clubs) and persistence. These parameters are treated as uncertain, and distributions are estimated using a Bayesian model and historical data for 113 countries over 118 years. The model is then used to estimate 2,000 economic projections for each of the 113 countries from 2018 to 2300.

These probabilistic economic growth projections are combined with the results of a formal expert elicitation of 10 leading macroeconomics and growth economists, conducted individually. As part of the elicitation, the experts first quantified their uncertainty for a set of calibration questions, the results of which were used to performance-weight the experts in the final combination. Experts demonstrated a

high level of statistical accuracy on the calibration questions. The elicitation focused on quantifying uncertainty for a representative frontier of economic growth in OECD countries for four years (2050, 2100, 2200, 2300). In general, the experts tended to agree with each other that median economic growth would slow between 2050 and 2300. Where experts tended to disagree was on the amount of uncertainty in future projections. However, 9 out of 10 of the experts estimated an uncertainty range that was narrower than the Müller et al. (2022) projections.

The performance-weighted combined results from the experts were then used to inform econometric projections based on the Müller et al. (2022) model of an evolving frontier (also based on the OECD), in turn providing country-level, long-run probabilistic projections. The first step in this procedure was to trim the Müller et al. (2022) projections based on the historical data and the results of the survey of experts. This was done in consultation with one of the authors (James Stock) of Müller et al. (2022). The remaining projections were then reweighted to fit the target quantiles from the performance-weighted combination of the experts. The expert judgement was given increasing weight over-time in the final RFF-SP projections. This aligns with the National Academies (2017) recommendations for combining statistical estimates with expert elicitation. Before 2030 the RFF-SP economic growth projections match the trimmed Müller et al. (2022) projections. The weight given to the expert judgement was increased linearly from 0% in 2030 to 100% in 2200. In 2200 and 2300, the reweighted Müller et al. (2022) projections match the quantiles of the performance-weighted expert judgement.

Global GHG emissions are projected using expert elicitation techniques (Rennert et al. 2022a).<sup>43</sup> A separate panel of 10 experts<sup>44</sup> having expertise in, and having undertaken, long-term projections of the energy-economic system under a substantial range of climate change mitigation scenarios were asked to provide future emissions projections. Like the economic growth survey these experts were asked a set of questions, with known answers, for calibration and performance weighting. Experts performed well on the calibration questions. Experts were then asked to provide uncertainty quantiles (minimum, 5<sup>th</sup>, 50<sup>th</sup>, 95<sup>th</sup>, maximum, as well as additional percentiles at the expert's discretion) for four emissions variables (i.e. fossil fuel and process-related CO<sub>2</sub> emissions, changes in natural CO<sub>2</sub> stocks and negative emissions technologies, CH<sub>4</sub>, N<sub>2</sub>O) in five benchmark years (2050, 2100, 2150, 2200, and 2300) and to indicate the sensitivity of the CO<sub>2</sub> emissions responses to five economic growth (i.e., GDP per capita) trajectories. Responses were requested under a case labeled "Evolving Policy" that incorporates views about changes in technology, fuel use, and other conditions, including the expected evolution of future policy.<sup>45</sup>

To better understand what factors experts were considering when providing their answers, experts were asked to describe their rationale (Rennert et al. 2022a). Experts had different rationales for fossil fuel and process-related CO<sub>2</sub> emissions estimates in low economic growth scenarios. Low economic growth should reduce emissions but may reduce policy ambitions and technological progress. This resulted in a wide

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<sup>43</sup> For greenhouse gases other than CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O that are needed as inputs to FaIR (e.g., CF<sub>4</sub>, C<sub>2</sub>F<sub>6</sub>, HFCs, CFCs, HCFCs), emissions are projected using SSP2-4.5 from AR6. This scenario is also used to calibrate FaIR1.6.2 and is nearest to the RFF-SP median emissions for carbon dioxide and methane. EPA is investigating the potential to use an emissions infilling tool such as Silicone (Lamboll et al. 2020) to extend the RFF-SP uncertainty analysis to other gases and aerosols.

<sup>44</sup> More information about the experts is provided in Rennert et al. (2022a) and the accompanying online appendix.

<sup>45</sup> See Rennert et al. (2022a) and the accompanying online appendix for a detailed discussion of the survey methodology and the full elicitation protocol.

uncertainty range for these scenarios but on average they expected emissions to decline. To support the high-end emissions, it was common for experts to state that low economic growth could lead countries to revisit emission reduction pledges. In support of emissions estimates for average economic growth, experts primarily mentioned policy as the driver of emissions. Specifically, emissions were dependent on the likelihood that countries would meet their pledges under the Paris Agreement or even enhance their ambitions. Secondarily, technological evolution was also stated as a primary driver. Experts stated that high economic growth should increase emissions in the medium term (2050 or 2100) but could allow for rapid decarbonization. It was felt that high economic growth could allow for an enhancement of global climate policy goals. Several of the experts felt that given the nature of policy goals (e.g., absolute or percentage reductions) that emissions would be decoupled from economic growth. For additional information on experts' rationale for changes in natural CO<sub>2</sub> stocks and negative emissions technologies, CH<sub>4</sub>, and N<sub>2</sub>O please see the Rennert et al. (2022a) Appendix.

The projections from the RFF-SPs represent a state-of-the-art set of probabilistic socioeconomic and emissions scenarios based on high-quality data, robust statistical techniques, and expert elicitation. In addition, they cover a sufficient time horizon for estimating the SC-GHG and incorporate uncertainty over future background policies. As such, the RFF-SPs are consistent with the National Academies' recommendations on socioeconomic and emissions scenarios.

***Other Sources of Socioeconomic and Emissions Projections.*** The RFF-SPs represent a significant advancement over the now outdated and deterministic EMF-22 scenarios and offer improvements over other recently developed socioeconomic and emissions projections. The other probabilistic projections identified in this review are a library of scenarios generated using MIT's Emissions Prediction and Policy Analysis (EPPA) Model, coupled with expert elicitation (Abt Associates 2012, Marten 2014). These projections have the advantage that they rely on a comprehensive computable general equilibrium (CGE) model that captures key feedbacks and interdependencies across the sources of uncertainty. However, they were generated in 2012 and do not incorporate changes in the economy, emissions trends, and policies adopted over the past decade.<sup>46</sup>

Other socioeconomic and emissions projections developed since the EMF-22 exercise are deterministic and do not provide global projections over a time horizon sufficient for SC-GHG estimation. The most prominent deterministic projections come from the database of Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs).<sup>47</sup> The SSPs and RCPs are the result of a scenario

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<sup>46</sup> Recently, Morris et al. (2022) built on this work by updating a broad range of input probability distributions and using updated versions of EPPA and other underlying models to explore uncertainty in socio-economic conditions out to 2100. This paper utilizes four emissions ensemble scenarios: (1) business-as-usual (2) National Determined Contribution pledges. (3) 2 degrees C and (4) 1.5 degrees C. Due to the reliance on scenarios for emissions the distribution of annual GHG emissions does not cover the full range of possible outcomes (see Figure 4 in Morris et al., 2022). In addition, these emissions ensemble scenarios are not assigned a probability and therefore assumptions would be required for sampling across them.

<sup>47</sup> Some organizations also regularly produce forecasts of key socioeconomic variables and emissions, but these tend to be only for a few decades or some countries or regions (e.g., IEA, EIA). Some IAM researchers have constructed deterministic projections using disparate sources. For example, the inputs used in the latest version of the DICE model, DICE 2016, include economic growth projections based on a survey by Christensen et al. (2018), population data from the United Nations, and CO<sub>2</sub> emissions projections from Carbon Dioxide Information Analysis Center, with simple assumptions for extending each series post-2100 (Nordhaus 2017).

development effort that started in the late 2000s to replace the Special Report on Emission Scenarios (SRES) from the 1990s (used in the IPCC Third Assessment Report). The two components, SSPs and RCPs, were designed to be complementary. RCPs set pathways for GHG concentrations and, effectively, the amount of warming that could occur by the end of the century.<sup>48</sup> Many possible socio-economic futures may lead to the same RCP, so the SSPs are scenarios of projected socioeconomic global changes through 2100, based on potential future changes in quantitative elements, including population, education, urbanization, GDP, and technology. There are five SSPs, each consisting of a set of quantified measures of development and an associated narrative storyline. The storylines provide a qualitative description of plausible future conditions that drive the quantitative elements. Pairings of these illustrative SSP scenarios with RCPs have been widely used by the IPCC, the global scientific community, and researchers spanning a wide range of disciplines. For modeling exercises requiring emissions projections beyond 2100, such as for SC-GHG estimation, researchers commonly use emissions extensions provided by the Reduced Complexity Model Intercomparison Project (Nicholls et al. 2020). When population and economic growth projections beyond 2100 are necessary, researchers have used various methods to extend the SSPs to 2300, ranging from simple extrapolation assumptions (e.g., CIL 2023, Benveniste et al. 2020)<sup>49</sup> to empirically derived projection methods (e.g., Kikstra et al. 2021).<sup>50</sup> Use of deterministic scenarios, such as the SSP-RCP pairings, would prevent the SC-GHG estimates from capturing important aspects of climate risk, including its relationship to broader socioeconomic uncertainty, and from valuing that risk in a way that is consistent with economic theory and observed human behavior related to risk aversion.

Figure 2.1.1 and Figure 2.1.2 present the RFF-SP projections of population and economic growth through 2300. These figures also include a comparison to the SSPs for years 2020 to 2100. The SSPs have been used in IPCC reports and other applications.<sup>51</sup> The SSP projections presented in the figure for years beyond 2100 are based on three extrapolation methods recently used in the literature—Benveniste et al. (2020) for SSP1, SSP2, and SSP3 (dashed lines), Kikstra et al. (2021) for SSP1, SSP2, SSP3, and SSP5 (dotted lines), and CIL (2023) for SSP2, SSP3, and SSP5 (dashed-dotted lines)—illustrating the sensitivity to various extrapolation assumptions.

The mean (black solid line) and median (black dotted line) of the RFF-SP population projections follow an increasing trajectory through 2100, slightly higher than the SSP1, SSP2 and SSP5 projections, peaking at

<sup>48</sup> Four RCPs were used in the IPCC Fifth Assessment Report (2014a) that span a range of radiative forcing (watts per m<sup>2</sup>) in 2100 and are named for that forcing above the pre-industrial level (RCP2.6, RCP4.5, RCP6.0 and a high-end no-mitigation RCP8.5). The SSPs took longer to develop. The SSPs were published in 2016 and updated in 2018. They are available at: <https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=10>. The SSPs and some additional RCPs are being used in the IPCC Sixth Assessment Report (2021a). The three additional RCPs include RCP1.9 (which focuses on limiting warming to below 1.5C), RCP3.4 (an intermediate pathway between RCP2.6 and RCP4.5), and RCP7.0 which represents medium-to-high end of emissions range and is a baseline outcome rather than a mitigation target.

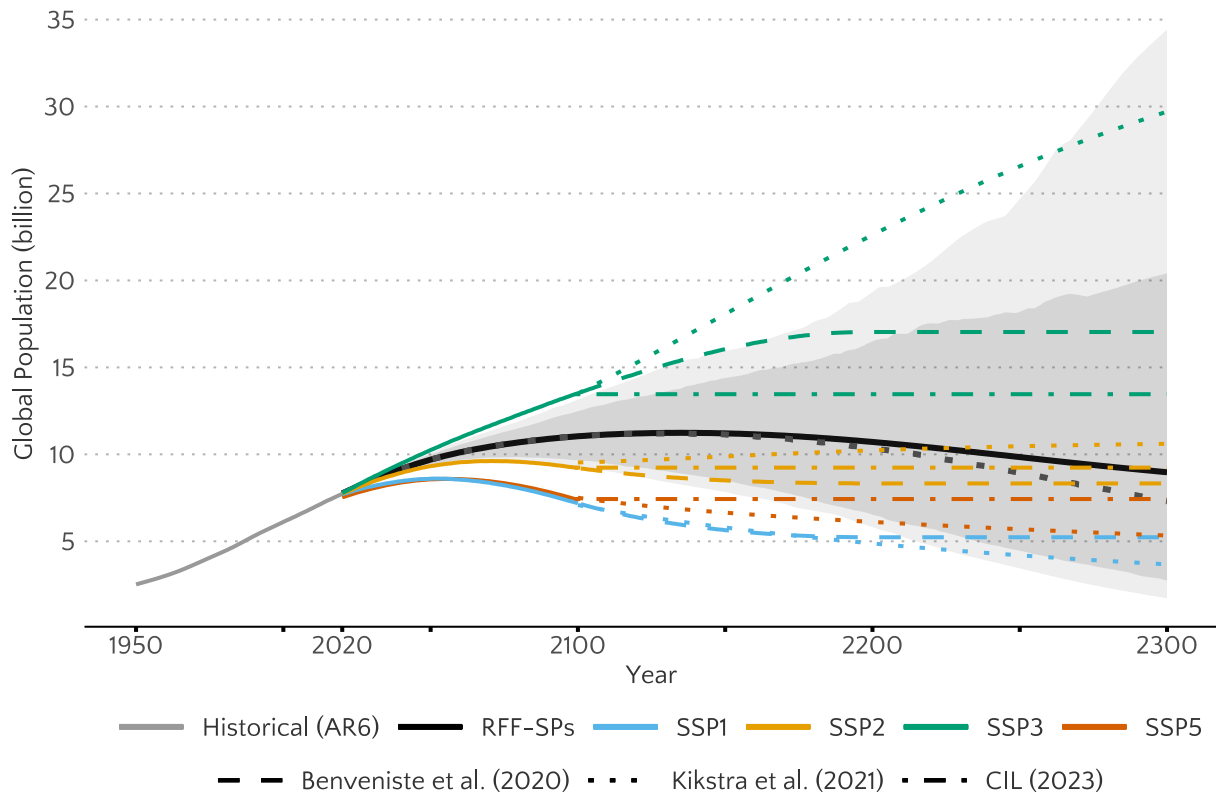
<sup>49</sup> In the components of their modeling that require extrapolation of GDP and population beyond 2100, when using SSPs, Climate Impact Lab (CIL 2023) modeling assumed GDP per capita growth and the level of global population remain constant at 2100 levels through 2300. Benveniste et al. (2020) generates country level extensions to 3000, based on the assumption that population growth declines linearly to 0 in 2200, and is held constant thereafter; GDP per capita growth is assumed to decline linearly reaching 0 in 2300.

<sup>50</sup> Kikstra et al. (2021) develop regional extensions based on the assumption that regional GDP per capita and population growth rates (in PAGE model regions) converge toward the global mean.

<sup>51</sup> Figures 2.1.1 and 2.1.2 contain all Tier 1 SSPs from IPCC AR6. Tier 2 scenarios, such as SSP4, were not considered.

11.2 billion people (Figure 2.1.1). This is followed by a slow decline to under 10 billion by 2300. SSP3 follows the upper tail of the RFF-SPs through 2100 and, depending on the extrapolation method, follows the upper tail or drops within the 99<sup>th</sup> and 95<sup>th</sup> percentile of the RFF-SP distribution by 2300. While the SSP-based projections shown in Figure 2.1.1 generally fall within or near the range of the RFF-SP probabilistic distribution for global population, they are limited in providing a comparison to the full RFF-SP distribution. The SSPs were intentionally developed to reflect a range of reasonably likely scenarios corresponding to different storylines rather than a more comprehensive range of plausible scenarios like the RFF-SPs. Furthermore, the SSP-based projections are sensitive to the extrapolation method used. For example, the SSP3 projections displayed in Figure 2.1.1 show global population in 2300 rising to about 13 billion under the CIL (2023) extrapolation, 17 billion under the Benveniste et al. (2020) extrapolation, and nearly 30 billion using Kikstra et al.'s (2021) method.

Figure 2.1.1: Global Population under RFF-SPs and SSPs, 1950-2300



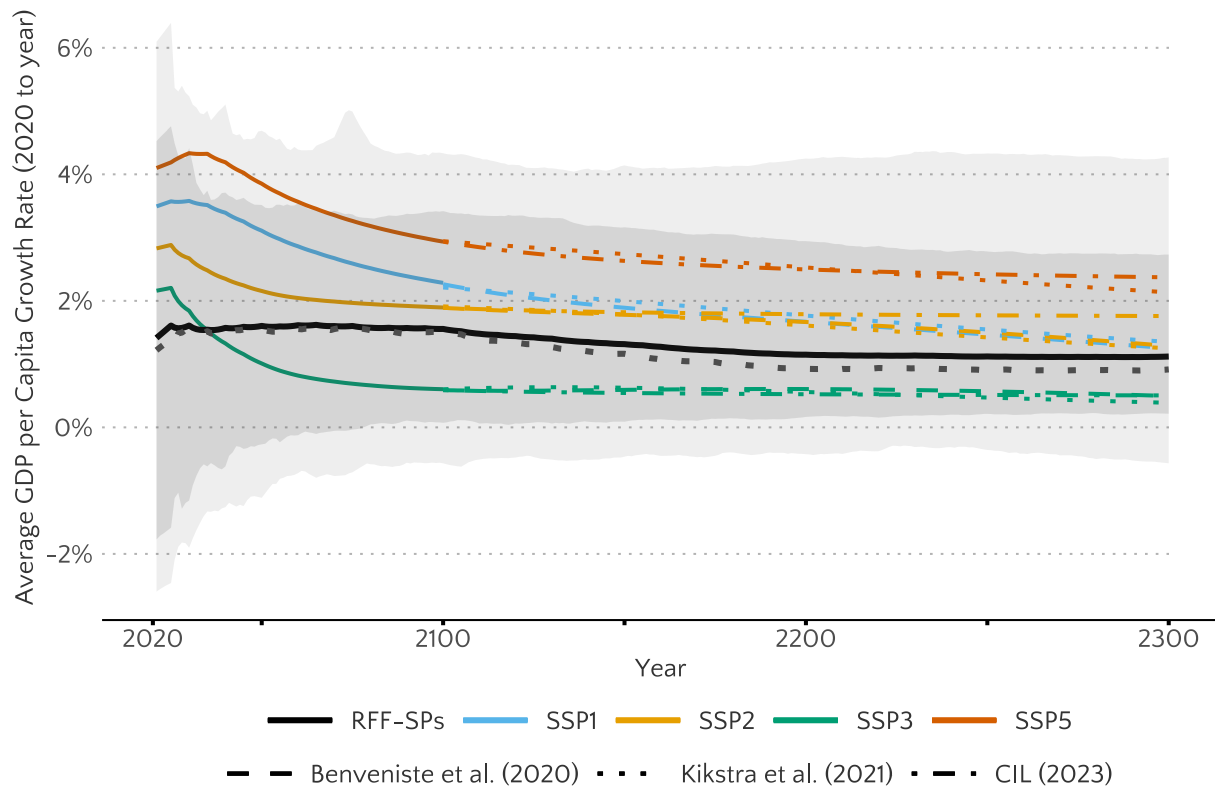
RFF-SP projections based on RFF-SPs (Rennert et al. 2022a). Black lines represent the mean (solid) and median (dotted) along with the 5<sup>th</sup> to 95<sup>th</sup> (dark shade) and 1<sup>st</sup> to 99<sup>th</sup> (light shade) percentile ranges. Historical data from Benveniste et al. (2020) using UN World Population Prospects 2019 (UN 2019). SSP1, SSP2, and SSP3 data through 2100 from Benveniste et al. (2020) using population growth rates from the International Institute for Applied Systems Analysis (IIASA) SSP Database (Riahi et al. 2017). SSP5 data through 2100 are from the IIASA database (Riahi et al. 2017). SSPs beyond 2100 (dashed) are based on three recent extrapolation methods: Benveniste et al. (2020), Kikstra et al. (2021), and CIL (2023).

Figure 2.1.2 presents the economic growth projections from the RFF-SPs along with comparisons to the SSPs in AR6.<sup>52</sup> The mean (black solid line) economic growth rates start at 1.4% in 2021, are relatively flat between 2030 and 2100 at 1.6% and then decline through-out the next century. The mean economic growth rate levels off again after 2200 at 1.1%. The RFF-SP economic growth projections are lower but most consistent with SSP2, i.e., the “middle of the road” scenario in which economic trends follow historical patterns. All the SSP-based projections displayed in Figure 2.1.2 lie within the long-run RFF-SP distribution. One notable difference between the RFF-SPs and the SSPs is the high near-term growth rates in the SSPs. Published in 2017, the SPPs economic growth projections are based on historical data through 2010. Between 2005 and 2010 the historical average annual growth rate was nearly 3%. The SSPs predicted an average annual growth rate between 2010 and 2019 of 2.89–2.96% (Riahi et al. 2017), whereas in the past decade average global per capita growth rates have been closer to 2% (World Bank 2021). The estimated growth-rates in the RFF-SPs are long-run growth rates, built to eliminate short-run fluctuations.

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<sup>52</sup> The growth rates (and the uncertainty bounds around the RFF-SPs) shown in Figure 2.1.2 are plotted in a time-averaged manner to accurately present the underlying year-on-year correlations that exist within each scenario/storyline.

Figure 2.1.2: Projections of Growth in Global Income per Capita under RFF-SPs and SSPs, 2020-2300



RFF-SP projections based on RFF-SPs (Rennert et al. 2022a). Black lines represent mean (solid) and median (dotted) growth rates along with 5<sup>th</sup> to 95<sup>th</sup> (dark shade) and 1<sup>st</sup> to 99<sup>th</sup> (light shade) percentile ranges. Historical data from Benveniste et al. (2020) using World Bank WDI (World Bank 2019). SSP data through 2100 from International Institute for Applied Systems Analysis (IIASA) SSP Database's OECD Env-Growth model (Riahi et al. 2017). SSPs beyond 2100 (dashed) are based on three recent extrapolation methods: Benveniste et al. (2020), Kikstra et al. (2021), and CIL (2023). The growth rates (and the uncertainty bounds around the RFF-SPs) are plotted in a time-averaged manner to accurately present the underlying year-on-year correlations that exist within each scenario/storyline.

Although the RFF-SPs displayed in the figures above are mostly consistent with the SSPs, there are notable advantages to the RFF-SPs. First, the economic growth and population projections are based on recent peer-reviewed statistical methodologies for generating long-term projections. These statistical projections represent advancements in the literature since the publication of the SSPs in 2017 and incorporate additional historical data beyond those used to calibrate the SSPs. Second, the RFF-SPs formally characterize the uncertainty in economic growth and population over time (less is known about the far-future than is known about the near-future). The SSPs are a set of deterministic scenarios and intentionally developed without probabilities attached to them, making them less suitable for addressing uncertainty. SSP-based economic growth projections, for example, vary depending on which of the three available alternative interpretations of the SSPs (using the IIASA, OECD, or PIK economic growth model) is selected from the SSP database. The SSP developers explicitly note that the provided “‘illustrative’ SSP should not be interpreted as the central or representative case....It is recommended to use the GDP



projections by all teams to test the sensitivity of the results due to different GDP assumptions.”<sup>53</sup> Third, the RFF-SPs provide projections over a much longer time horizon (out to 2300), which is relevant for capturing more of the discounted damages from climate change, whereas the SSPs provide projections out to 2100 and long term extrapolations of the SSPs developed by researchers to date are sensitive to the method used. Each of these advantages were highlighted by the National Academies (2017) as important elements in developing improved projections of socioeconomic variables and emissions. Thus, the RFF-SPs more closely implement the near-term recommendations from the National Academies on economic growth and population projections than do the SSPs.

In both the RFF-SPs and the SSPs, projections of global GDP are calculated using purchasing power parity (PPP). This represents a shift from the EMF-22 projections used to date, in which global GDP was based on combining regional GDPs using market exchange rates (MER). As discussed in the IWG’s 2010 TSD, PPP takes into account the different price levels and different baskets of goods consumed across countries, so it more accurately describes relative standards of living across countries. PPP-adjusted measures are increasingly available and used in climate economics research. For example, Nordhaus has argued since 2007 that “PPP measures are superior to MER measures for representing relative incomes and outputs” (Nordhaus 2007), and the update to his DICE model in 2016 included a shift from MER to PPP exchange rates (Nordhaus 2017, 2018a). Similarly, Anthoff and Emmerling (2019) maintain that “...using nominal or market exchange rates would overstate the (current) degree of inequality between countries compared to the measurements using PPPs.” The shift to PPP-based projections in the RFF-SPs, therefore, represents another advancement in the science underlying the SC-GHG framework presented in this report.

In the SSPs and the mean RFF-SPs, global emissions of CO<sub>2</sub> peak at some point this century and decline toward zero emissions (in some cases negative emissions). These emission peaks for the SSPs are based on simplistic assumptions about net emissions reaching zero in 2250. The RFF-SP projections are based on expert elicitation, where the experts were asked to incorporate their views on the evolution of future policy. This is consistent with the National Academies’ (2017) recommendations to “take account of the likelihood of future emissions mitigation policies.” Because the RFF-SPs are probabilistic they reflect the uncertainty in future policy and when this peak would occur. In the mean RFF-SP projection the peak occurs this decade. In some of the higher emissions scenarios this peak in emissions does not occur until near the end of the century.

Figure 2.1.3 presents the RFF-SP projections for CO<sub>2</sub> emissions through 2300 along with a comparison to a range of SSP-RCPs from AR6 (Figure A.6.1 and Figure A.6.2 in the Appendix present the same information for CH<sub>4</sub> and N<sub>2</sub>O emissions through 2300). For SSP-RCP pairings presented in the figure, emissions projections beyond 2100 are based on the commonly used extensions provided by the Reduced Complexity Model Intercomparison Project (Nicholls et al. 2020). The post-2100 SSP projections are based on simplistic assumptions about when global emissions reach zero (2055 for SSP1-1.9, 2075 for SSP1-2.6, 2250 for SSP2-4.5, SSP3-7.0, and SSP5-8.5) and how global emissions reach this point after 2100. In the mean RFF-SPs (black solid line) global CO<sub>2</sub> emissions continue to rise in the near-term but peak at 42 GtCO<sub>2</sub> before 2030. Both the RFF-SP median and the mean track closely with SSP2-4.5, which is often described as a “middle of the road” SSP storyline. The SSP5-8.5 projection is the only SSP-RCP pairing with CO<sub>2</sub>

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<sup>53</sup> See SSP Database (Shared Socioeconomic Pathways) - Version 2.0 available at: <https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=10>.

emissions projections outside the 1<sup>st</sup> to 99<sup>th</sup> percentile range of RFF-SPs. The RCP8.5 emissions scenario is a high emissions scenario in absence of climate change policies (Riahi et al. 2017).<sup>54</sup> As mentioned above, the RFF-SPs explicitly account for the likelihood of future climate policies.<sup>55</sup> While the SSP-RCP scenarios offer plausible storylines that imbed these assumptions within their trajectories, the RFF-SPs have a significant advantage in that they assign probabilities to these future policies and their outcomes, account for adoption of cleaner technologies and fuel sources, and explicitly link socioeconomic growth scenarios to emissions.<sup>56</sup>

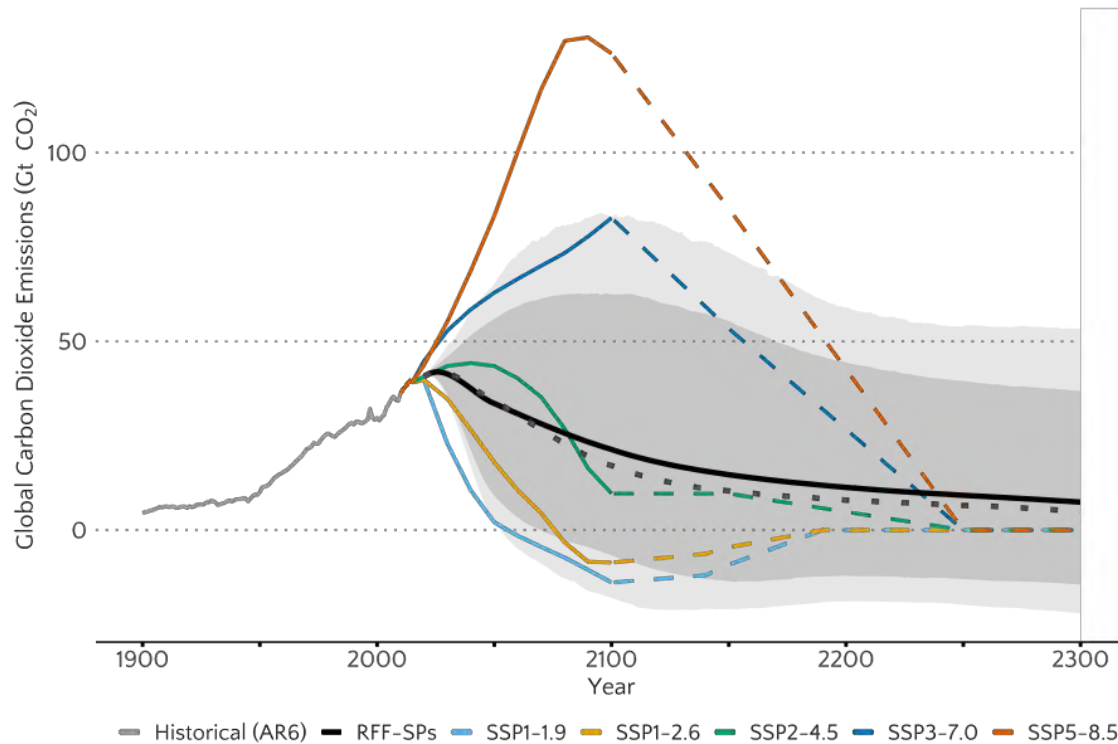
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<sup>54</sup> While all the RCP emissions scenarios peak and begin to decline by, or shortly after, the end of the century, it is important to note that CO<sub>2</sub> concentrations, and therefore temperatures, will not stabilize until CO<sub>2</sub> emissions decline to zero (Matthews and Caldeira 2008).

<sup>55</sup> Specifically, Rennert et al (2022a) states: “...experts viewed low economic growth as likely to reduce emissions overall but also lead to reduced global ambition in climate policy and slower progress to decarbonization. For median economic growth conditions, experts generally viewed policy and technology evolution as the primary driver of their emissions distributions, often offering a median estimate indicating reductions from current levels but with a wide range of uncertainty. Several experts said high economic growth would increase emissions through at least 2050, most likely followed by rapid and complete decarbonization, but with a small chance of substantial continued increases in emissions.”

<sup>56</sup> Throughout all stages of the SC-GHG modeling process, we compared the intermediate and final outputs across the SSP-RCP socioeconomic and emissions storylines and the RFF-SP probabilistic scenarios. For each of these outputs (global mean surface temperature, sea level rise, and even the final SC-GHG estimates) the 5<sup>th</sup> and 95<sup>th</sup> percentiles of the RFF-SPs lie within the full range of the SSP-RCP storylines and are most consistent with the SSP2-RCP4.5 pairing. In addition, a comparison of the RFF-SP emissions projections with the EMF-22 trajectories used in the IWG-recommended SC-GHG estimates to date is displayed in Appendix A.6. Figure A.6.3 illustrates that the RFF-SP based CO<sub>2</sub> emissions range lie within the low end of the range of the selected EMF-22 scenarios, likely reflecting the impact of GHG mitigation policies and other factors that have occurred since the development of the EMF-22 trajectories and that the RFF-SPs reflect the possibility of future policies whereas only one of the five selected EMF-22 scenarios did so.

Figure 2.1.3: Net Annual Global Emissions of Carbon Dioxide (CO<sub>2</sub>) under RFF-SPs and SSPs, 1900-2300



RFF-SP projections based on RFF-SPs (Rennert et al. 2022a). Black lines represent the mean (solid) and median (dotted) CO<sub>2</sub> emissions projections along with 5<sup>th</sup> to 95<sup>th</sup> (dark shade) and 1<sup>st</sup> to 99<sup>th</sup> (light shade) percentile ranges. SSP data through 2100 are from the International Institute for Applied Systems Analysis (IIASA) SSP Database (Riahi et al. 2017). SSPs beyond 2100 (dashed lines) are based on the commonly used extensions provided by the Reduced Complexity Model Intercomparison Project (Nicholls et al. 2020).

## 2.2 Climate Module

The next step in the SC-GHG estimation process is to estimate the effect of emissions on physical climate variables, such as temperature, and to ensure that the outputs from the climate model are at the spatial and temporal resolution required by the damage module. This means the climate module must:

- (1) translate GHG and other forcing agent emission projections into atmospheric concentrations, accounting for the uptake of CO<sub>2</sub> by the land biosphere and the ocean and the removal of other greenhouse gases through atmospheric reactions, deposition, and/or other mechanisms;
- (2) translate concentrations of greenhouse gases and other forcing agents into radiative forcing;
- (3) translate forcing into global mean surface temperature response, accounting for heat uptake by the ocean, and
- (4) generate other climatic variables, such as sea level rise (SLR), that may be needed by the damage module.<sup>57</sup>

<sup>57</sup> This module could in future iterations also generate estimates of other climatic variables (e.g., precipitation changes) as well as non-climate mediated impacts of GHG emissions if needed as inputs to future damage functions.

Together, with the projections of associated socioeconomic variables, the results from the climate module serve as inputs to the damage module.

As discussed in section 1.1, the methodology underlying SC-GHG estimates used in the EPA's analyses to date has included a representation of climate and other Earth system dynamics as provided in the default version of the DICE, FUND, and PAGE IAMs. The only climate variable that was harmonized across these three previous models was equilibrium climate sensitivity (ECS) – a measure of the globally averaged temperature response to increased radiative forcing.<sup>58</sup> Each IAM was run using a probability distribution for the ECS, calibrated to the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report (AR4) (IPCC 2007a) findings using the Roe and Baker (2007) distribution.<sup>59</sup> All other aspects of the modeling – such as the representation of the carbon cycle and its parameterization, sea level rise, regional downscaling of temperature, and treatment of non-CO<sub>2</sub> greenhouse gases – varied across the three IAMs and were used as the model developers had designed them.

To implement a modular approach to updating the representation of climate and other Earth system dynamics in SC-GHG estimation, it is helpful to review the available climate models capable of meeting the climate module requirements outlined above, the conclusions of recent scientific assessments published since the IPCC's AR4 report, the public comments received on individual EPA proposed rulemakings and the IWG's February 2021 TSD (IWG 2021), and the National Academies (2017) recommendations related to the climate module.

The conclusions of recent scientific assessments (e.g., IPCC 2014a, 2018, 2019a, 2019b, 2021a; USGCRP 2016, 2018a; and the National Academies 2016b, 2019) bolster the science underlying the modeling of climate dynamics. Recently, in August 2021, the IPCC released the Working Group (WG) 1 contribution to the IPCC Sixth Assessment Report (AR6) (IPCC 2021a). The IPCC (2021a) report brings together the most up-to-date physical understanding of the climate system and climate change. The report includes updated IPCC AR6 consensus statements on key climate parameters that are relevant for SC-GHG estimation, including equilibrium climate sensitivity and transient climate response. For ECS, the AR6 assessment finds, with high confidence, that the best estimate is 3°C with a likely range of 2.5°C to 4°C.<sup>60</sup> AR6 also

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As discussed in Section 3.3, the only non-climate mediated effect included in SC-GHG estimates used by the EPA to date are plant fertilization effects from elevated CO<sub>2</sub> concentrations. Other non-climate mediated effects of GHG emissions that have not yet been incorporated into SC-GHG estimation are discussed in Section 4.2.

<sup>58</sup> ECS is defined as “the equilibrium (steady state) change in the surface temperature following a doubling of the atmospheric carbon dioxide (CO<sub>2</sub>) concentration from pre-industrial conditions” (IPCC 2021a).

<sup>59</sup> The IPCC's Fourth Assessment Report (IPCC 2007b) was the most current IPCC assessment available at the time when the IWG calibrated the ECS distribution.

<sup>60</sup> The AR6 assessment finds “[b]ased on multiple lines of evidence, the very likely range of equilibrium climate sensitivity is between 2°C (high confidence) and 5°C (medium confidence). The AR6 assessed best estimate is 3°C with a likely range of 2.5°C to 4°C (high confidence), compared to 1.5°C to 4.5°C in AR5, which did not provide a best estimate” (IPCC 2021a). In IPCC statements, the terms “likely”, “very likely” and “virtually certain” are defined to correspond to probabilities of at least 66% (16.6-83.3 percentile), 90% (5-95 percentile), and 99% (0.5-99.5 percentile), respectively (IPCC 2007c). In IPCC reports, a level of confidence is expressed using five qualifiers (very low, low, medium, high, and very high) based on the type, amount, quality, and consistency of evidence (e.g., mechanistic understanding, theory, data, models, expert judgement) and on the degree of agreement across multiple lines of evidence. Statements in the AR6 WG1 report that include “best estimate” are not specific on its definition.

concludes that “it is virtually certain that ECS is larger than 1.5°C, but currently it is not possible to rule out ECS values above 5°C” (IPCC 2021a). As cited in IPCC (2021a), Sherwood et al. (2020) present several lines of evidence supporting these assessments of equilibrium climate sensitivity. For the transient climate response (TCR), AR6 finds that the best estimate of TCR is 1.8°C, and it is very likely between 1.2 and 2.4°C.<sup>61</sup> Additional discussion of scientific updates in AR6 is provided in the Appendix. In particular, Section A.1 contains a summary of the IPCC’s understanding of CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O greenhouse gas radiative efficiency, atmospheric lifetimes, and chemistry in AR6 relative to AR4, which was the basis of the simplified lifetime and forcing equations underlying the IWG estimates used by the EPA and other federal agencies to date.

Reduced-complexity climate models (RC models) offer meaningful improvements over the current representation of climate dynamics in existing IAMs (Nicholls et al. 2020). RC models are highly parameterized, computational emulators of the climate system. RC models are different from the highly complex and computationally demanding Earth system models (ESMs), which are the state-of-the-art tools for climate projections. However, the use of RC models may be preferred over ESMs for certain applications for at least three reasons: (1) the computational efficiency of the RC models allows for hundreds or thousands of simulations in a relatively short timeframe, (2) the adjustability of model parameters allows for the exploration of uncertainty, and (3) because RC models do not model year-to-year variability they allow for the estimation of the difference between emission scenarios that would be smaller than that variability (Sarofim et al. 2021a). RC models have a long history of use in climate science assessments, IAM modeling applications, and analyses of climatic processes. They are ubiquitously used to support model inter-comparisons and diagnostics because of their ability to emulate different ESM components and variables, explore uncertainties in key climate parameters, analyze scenarios to provide concentration and temperature inputs to IAMs and other models, and estimate climate sensitivity when coupled with historical climate observations (Nicholls et al. 2020, Nicholls et al. 2021, Sarofim et al. 2021a).

One of the most widely used RC models is the Finite amplitude Impulse Response (FaIR) climate model (Millar et al. 2017, Smith et al. 2018) to generate projections of global mean surface temperature (GMST) change. The FaIR model was originally developed by Richard Millar, Zeb Nicholls, and Myles Allen at Oxford University, as a modification of the approach used in IPCC AR5 to assess the GWP and GTP (Global Temperature Potential) of different gases. It is open source, widely used (e.g., IPCC 2018, IPCC 2021b), and was highlighted by the National Academies (2017) as an RC model that satisfies their recommendations for a near-term update of the climate module in SC-GHG estimation. Specifically, it translates GHG emissions into mean surface temperature response following the steps outlined above and represents the current understanding of the climate and GHG cycle systems and associated uncertainties within a probabilistic framework. The FaIR model’s projections of future warming are consistent with more complex, state of the art ESMs and can, with high confidence, be used to accurately

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<sup>61</sup> TCR is defined as “the surface temperature response for the hypothetical scenario in which atmospheric carbon dioxide (CO<sub>2</sub>) increases at 1% yr<sup>-1</sup> from pre-industrial to the time of a doubling of atmospheric CO<sub>2</sub> concentration” (IPCC 2021a), thereby being a measure of the speed as well as the magnitude of the climate response. AR6 states that “Based on process understanding, warming over the instrumental record and emergent constraints the best estimate TCR is 1.8°C, it is likely 1.4 to 2.2°C and very likely 1.2 to 2.4°C” (IPCC 2021a).

characterize current best understanding of uncertainty, is easily implemented, and is transparently documented.

The updated SC-GHG estimates presented in this report rely on FaIR version 1.6.2 as used by the IPCC (2021a, 2021b). An alternative version of the model, FaIR 2.0, was recently published (Leach et al. 2021) that offers some advantages with respect to simplicity and the inclusion of a flexible, state-dependent methane lifetime, but is less preferable for SC-GHG estimation at this time because it is not yet able to track ocean heat uptake (which is used as an input to help project future sea level rise in some models such as the Building Blocks for Relevant Ice and Climate Knowledge (BRICK) model discussed below); importantly the calibration of its uncertain parameters is based on historical data but has not yet been adjusted to be consistent with the AR6 evaluation of climate characteristics such as the IPCC assessed likely range of 2.5 to 4°C for the climate sensitivity. FaIR 1.6.2 also has advantages over the latest versions of other RC models, including the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC; Meinshausen et al. 2011) and the Hector model, a U.S. Government-developed model (Hartin et al. 2015).<sup>62</sup> MAGICC is widely used in science research, policy analysis, IPCC reports, and the latest version, MAGICC 7.5.1, has been calibrated to AR6 findings. However, the model itself is not open source and, therefore, less preferable to FaIR in terms of transparency and reproducibility. The Hector model has some additional complexity and features that could be helpful in future SC-GHG updates. For example, it can emulate ocean acidification, permafrost, and land carbon cycles (Woodard et al. 2021). However, Hector has not yet been calibrated to the AR6 assessed climate characteristic ranges, and the current version of Hector has no suggested parameter sets for use in uncertainty analysis. Table 2.2.1 shows summary statistics for the ECS from the FaIR 1.6.2 model used in this report and other RC models and compares them to IPCC statements. For reference, Table 2.2.1 also includes the assumed distribution used in IWG SC-GHG estimates to date. Table 2.2.2 shows similar information for the TCR. FaIR, MAGICC, and Hector have all been tested against the Earth system models used by the IPCC as part of the Reduced Complexity Model Intercomparison Project (RCMIP) (Nicholls et al. 2020).<sup>63</sup> Nicholls et al. compare the global-mean temperature response across a range of perturbations. The authors demonstrate the success of all three models in estimating the global mean temperature for applications in integrated assessment modeling.

Taken together, FaIR 1.6.2 is a fitting RC model to serve as the basis for an updated climate module in SC-GHG estimation. It provides, with high confidence, an accurate representation of the latest AR6 scientific consensus on the relationship between global emissions and global mean surface temperature under the wide range of socioeconomic emissions scenarios discussed in Section 2.1. It also offers a code base that is fully transparent and available online (unlike MAGICC), and the uncertainty capabilities in FaIR 1.6.2

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<sup>62</sup> FaIR and MAGICC were among the four RC models examined in IPCC (2021a), along with Oscar (Gasser et al. 2020), and Cicero-SCM (Skeie et al. 2021). Each of these were calibrated based on agreement with observations such as historical temperatures, ocean heat uptake, CO<sub>2</sub> concentrations, and airborne fraction. The WG1 report compares distributions from the calibrated models to assessed values of metrics such as ECS and TCR. The latter two RC models are dropped from detailed consideration in this report because Cicero-SCM does not have a carbon cycle representation, and Oscar did not match projected future temperatures from the Coupled Model Intercomparison Project (CMIP) and other projections. Thompson (2018) also identified FaIR, MAGICC, and Hector as being good fits to the National Academies' recommended criteria for the climate module.

<sup>63</sup> See also: <https://www.rcmip.org/>.

have been calibrated to the most recent assessment of the IPCC (which importantly narrowed the range of likely climate sensitivities relative to prior assessments) (unlike FaIR2.0 or Hector at the present time).

*Table 2.2.1: Summary Statistics for Equilibrium Climate Sensitivity under Reduced-Complexity Climate Models and IPCC statements*

|                                                                | Percentiles and Other Summary Statistics |       |                   |                   |      |             |
|----------------------------------------------------------------|------------------------------------------|-------|-------------------|-------------------|------|-------------|
|                                                                | 5%                                       | 16.6% | Mode <sup>a</sup> | Median (50%)      | Mean | 83.3% 95%   |
| FaIR 1.6.2 <sup>d</sup>                                        | 2.05                                     | 2.37  | 2.78              | 2.95              | 3.18 | 3.87 5.03   |
| FaIR 2.0.0 (Leach et al. 2021)                                 | 1.94                                     | 2.36  |                   | 3.24              |      | 4.74 6.59   |
| MAGICC7 (IPCC 2021a)                                           | 1.93                                     |       |                   | 2.97              |      | 4.83        |
| Hector2.5 (Nicholls et al. 2021)                               | 1.84                                     | 2.16  |                   | 2.85              |      | 3.90 5.45   |
| AR6 statement (IPCC 2021b)                                     | 2.00                                     | 2.50  |                   | 3.00 <sup>b</sup> |      | 4.00 5.00   |
| AR5 statement (IPCC 2013)                                      | > 1.00                                   | 1.50  |                   |                   |      | 4.50 < 6.00 |
| IWG to date (Roe & Baker (2007), calibrated to AR4) (IWG 2010) | 1.72                                     | 2.00  | 2.34              | 3.00              | 3.50 | 4.50 7.14   |
| AR4 statement (IPCC 2007b)                                     |                                          | 2.00  |                   | 3.00 <sup>c</sup> |      | 4.50        |

<sup>a</sup> Mode calculated after rounding to 2 decimal places.

<sup>b</sup> AR6 offers a “best estimate” but is not specific on which statistic for central value most closely corresponds to “best”.

<sup>c</sup> AR4 offers a “most likely” value. As noted in IWG (2010), strictly speaking, “most likely” refers to the mode of a distribution rather than the median, but common usage would allow the mode, median, or mean to serve as candidates for the central or “most likely” value and the IPCC report is not specific on this point.

<sup>d</sup> Results from FaIR 1.6.2 were estimated using the 2,237 constrained parameter sets. The shading in the table helps to highlight how the model used in this report (FaIR1.6.2) compares with the latest scientific consensus (AR6) on this key parameter.



*Table 2.2.2: Summary Statistics for Transient Climate Response under Reduced-Complexity Climate Models and IPCC Statements*

|                                  | Percentiles and Other Summary Statistics |       |                   |              |      |           |
|----------------------------------|------------------------------------------|-------|-------------------|--------------|------|-----------|
|                                  | 5%                                       | 16.6% | Mode <sup>a</sup> | Median (50%) | Mean | 83.3% 95% |
| FaIR 1.6.2 <sup>b</sup>          | 1.36                                     | 1.49  | 1.60              | 1.81         | 1.85 | 2.20 2.46 |
| FaIR 2.0.0 (Leach et al. 2021)   | 1.30                                     | 1.48  |                   | 1.79         |      | 2.15 2.44 |
| MAGICC7 (IPCC 2021a)             | 1.27                                     |       |                   | 1.88         |      | 2.61      |
| Hector2.5 (Nicholls et al. 2021) | 1.42                                     | 1.58  |                   | 1.82         |      | 2.08 2.29 |
| AR6 statement (IPCC 2021b)       | 1.20                                     | 1.40  |                   | 1.80         |      | 2.20 2.40 |
| AR5 statement (IPCC 2013)        |                                          | 1.00  |                   |              |      | 2.50 3.00 |
| AR4 statement (IPCC 2007b)       | 1.00                                     |       |                   |              |      | 3.00      |

<sup>a</sup> Mode calculated after rounding to 2 decimal places.

<sup>b</sup> Results from FaIR 1.6.2 were estimated using the 2,237 constrained parameter sets. The shading in the table helps to highlight how the model used in this report (FaIR1.6.2) compares with the latest scientific consensus (AR6) on this key parameter.

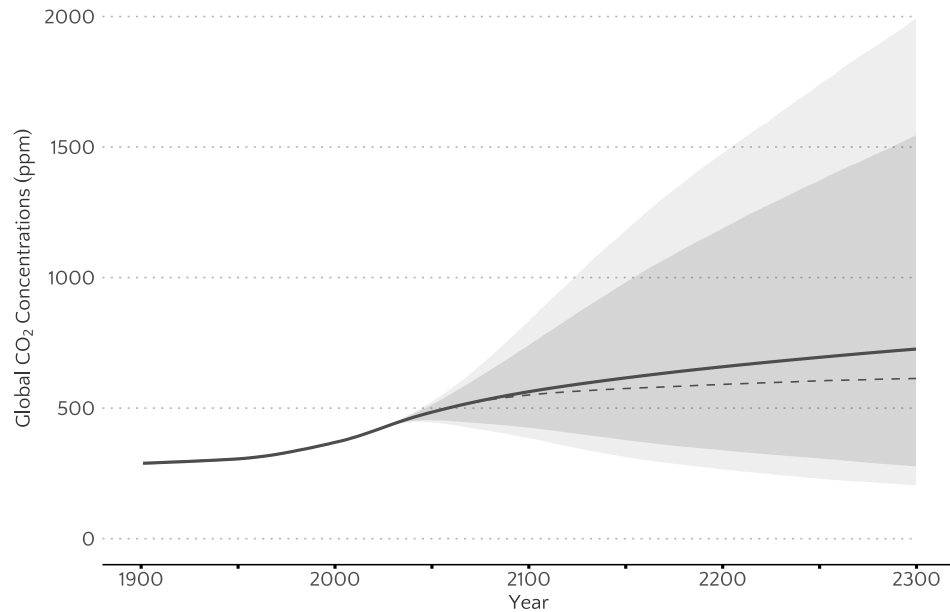
Figure 2.2.1 shows the projected future atmospheric concentration<sup>64</sup> of CO<sub>2</sub> through 2300 based on the RFF-SP emissions projections that are used as inputs into FaIR 1.6.2. Atmospheric concentrations increase over time due to the accumulation of annual emissions, with excess CO<sub>2</sub> from the atmosphere moving into the ocean and ecosystems slowly over time until eventually a new equilibrium is reached.<sup>65</sup> Figure 2.2.2 shows the corresponding projection of global mean surface temperature. The ranges in these figures reflect uncertainty in both emissions and physical climate processes that are consistent with the latest projections coming out of the Sixth Assessment Report (IPCC 2021a).<sup>66</sup>

<sup>64</sup> Atmospheric concentration refers to the amount of a gas in the atmosphere. For CO<sub>2</sub>, it is measured in parts per million (ppm). Pre-industrial concentrations of CO<sub>2</sub> were 280 ppm, and concentrations this high have not been seen in at least 2 million years.

<sup>65</sup> Figure A.6.6 and Figure A.6.7 in the Appendix show projected atmospheric concentrations of methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O). CH<sub>4</sub> and N<sub>2</sub>O concentrations are higher than at any time in at least 800,000 years. While CO<sub>2</sub>, once emitted into the atmosphere through combustion, is not destroyed but rather moves between the ocean, ecosystems, and atmosphere, other gases like CH<sub>4</sub> and N<sub>2</sub>O are destroyed through reactions in the atmosphere.

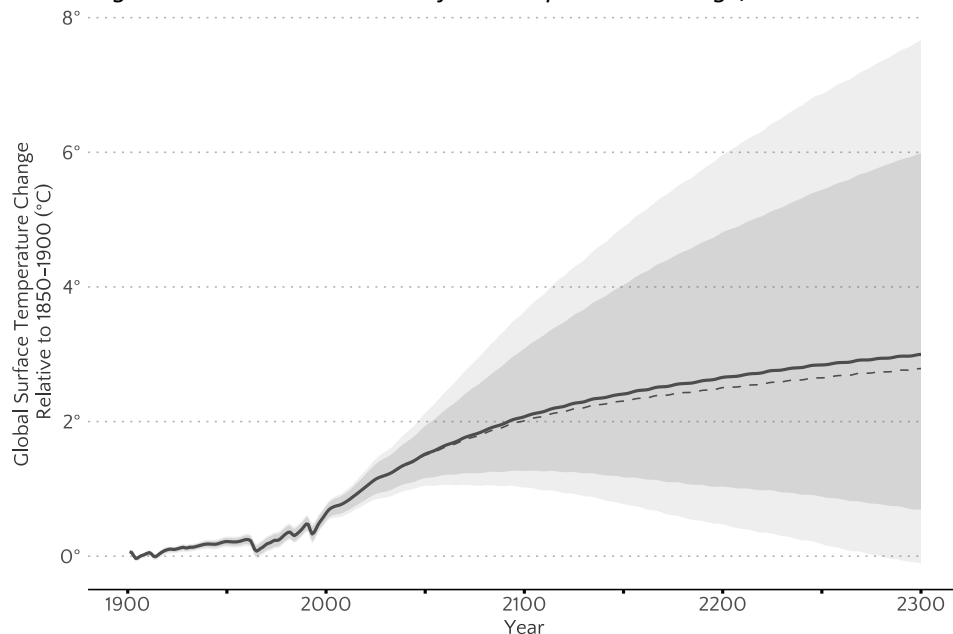
<sup>66</sup> FaIR has a number of uncertain parameters that are chosen to be compatible with each other. For example, if some parameters in a given model run result in higher climate sensitivity, then it is likely that other parameters will result in more heat uptake by the ocean. This will ensure that the overall parameter selection is still consistent with historical temperatures. Higher heat uptake by the ocean results in the Earth's surface taking longer to reach its new equilibrium temperature, but faster sea level rise due to thermal expansion happening earlier.

**Figure 2.2.1: Global Atmospheric Concentrations of Carbon Dioxide (CO<sub>2</sub>), 1900-2300**



Future atmospheric concentrations of carbon dioxide (CO<sub>2</sub>) are based on the range of annual emissions projections from the sampled RFF-SP scenarios used as inputs into FaIR 1.6.2. FaIR 1.6.2 is run with the full, AR6 calibrated (constrained) uncertainty distribution. Therefore, the uncertainty ranges in this figure represent both emissions and physical carbon cycle uncertainty. Mean (solid) and median (dashed) lines are shown along with the 5<sup>th</sup> to 95<sup>th</sup> (dark shade) and 1<sup>st</sup> to 99<sup>th</sup> (light shade) percentile ranges.

**Figure 2.2.2: Global Mean Surface Temperature Change, 1900-2300**



The range of global mean surface temperature change relative to pre-industrial (1850-1900) as calculated by FaIR 1.6.2 corresponding to the CO<sub>2</sub> concentrations from Figure 2.2.1 and the accompanying figures for CH<sub>4</sub> and N<sub>2</sub>O in the Appendix. Uncertainty comes from emissions uncertainty from the RFF-SP projections and physical climate uncertainty from FaIR. Mean (solid) and median (dashed) lines are shown along with the 5<sup>th</sup> to 95<sup>th</sup> (dark shade) and 1<sup>st</sup> to 99<sup>th</sup> (light shade) percentile ranges.

Because the SC-GHG is calculated based on the impact of a marginal pulse of emissions, it is particularly relevant to investigate how the climate model responds to a change in emissions.<sup>67</sup> The response of the climate to a pulse of GHG emissions (i.e., CO<sub>2</sub>, CH<sub>4</sub>, or N<sub>2</sub>O) is calculated by using a reference scenario (baseline) and subtracting the temperatures of that reference scenario from a second scenario (perturbed) that is identical in all dimensions except for the marginal increase in emissions for the one year and one gas being examined (i.e., all characteristics of the model run, emissions levels of other gases, etc., are held constant for the duration of the perturbed model run). Figure 2.2.3 shows the temperature response resulting from a pulse of CO<sub>2</sub> emissions in 2030 under the three RC models considered in this report.<sup>68</sup> The FaIR, MAGICC, and Hector model outputs all exhibit similar dynamics in the timing of peak warming in response to a pulse of emissions. For most gases, a pulse of emissions leads to a peak in temperature within a few years following the pulse of emissions. Then, as the radiative forcing declines and the ocean heat uptake increases, the marginal increase in temperature begins to decline at an increasing rate. However, as illustrated in Figure 2.2.3, the temperature response to a pulse of CO<sub>2</sub> is a little more complicated. When the rate of decrease in radiative forcing slows such that the rate of decline in ocean heat uptake exceeds it, atmospheric warming resumes leading to a sustained increase in temperature.<sup>69</sup> The temperature dynamics of these models better reflect the established conclusions of state of the art climate modeling tools used in international scientific assessments than the temperature responses underlying the climate components of the three IAMs used in the IWG SC-GHG estimates. Specifically, Dietz et al. (2021a) showed that the initial response of DICE, FUND, and PAGE to a pulse of CO<sub>2</sub> emissions was slower than the response of FaIR calibrated to 256 models involved in the fifth phase of the Coupled Model Intercomparison Project (CMIP5<sup>70</sup>), demonstrating that FaIR and related models can better emulate the high-resolution global climate models. This is an important feature when estimating the SC-GHG as discussed in Section 2.4 (near term marginal damages are discounted less than

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<sup>67</sup> The pulse sizes used for the model runs in this report were selected to be the smallest size that the climate system model will reasonably represent and where the damage functions are responding on the margin. See Section 2.3 for more discussion of each damage function used in this update.

<sup>68</sup> Figure A.6.8 and Figure A.6.9 in the Appendix show the temperature response resulting from a pulse of CH<sub>4</sub> and N<sub>2</sub>O emissions.

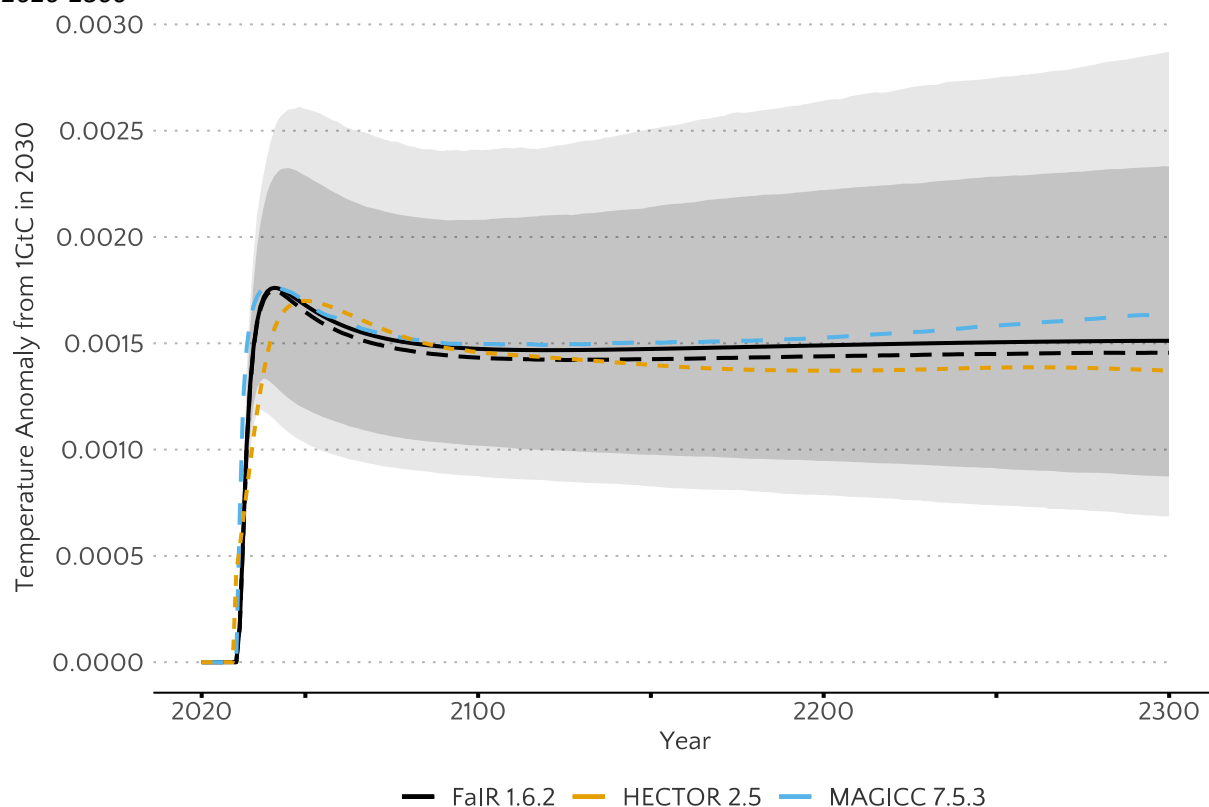
<sup>69</sup> A more detailed explanation of the temporal temperature response resulting from a pulse of greenhouse gas emissions is as follows. The atmospheric concentration response from an emissions release is the highest at time zero and declines thereafter as the gas either decomposes in the atmosphere or cycles into other reservoirs. The radiative forcing is directly related to the increased concentration. However, the temperature response is a function of the accumulation of energy due to the radiative forcing, minus the heat that the ocean takes up as the atmosphere warms and the increased heat that is radiated to space due to a warmer planet. For most gases, this balance between radiative heating from the gas and heat uptake by the ocean leads to a peak in temperature within a few years of the emission as the radiative forcing declines and the ocean heat uptake increases. The decline in temperature lags the decline in radiative forcing, as the heat that went into the ocean is eventually released. However, the response to a pulse of CO<sub>2</sub> is a little more complicated: because the elevated concentrations resulting from a pulse of CO<sub>2</sub> emissions decreases quickly to start as CO<sub>2</sub> cycles into the ecosystems and surface oceans, but then the decrease slows as the timescale becomes dominated by deep ocean mixing and slows further when it is dominated by sedimentation. When the rate of decrease in radiative forcing slows such that the rate of decline in ocean heat uptake exceeds it, atmospheric warming resumes creating a second peak in temperature (Millar et al. 2017).

<sup>70</sup> CMIP is the Coupled (sometimes, Climate) Model Intercomparison Project. CMIP creates a framework for consistent application of climate models to a common set of scenarios, and with a common set of outputs, to facilitate assessment of these models and provide consistent inputs to impacts assessments. CMIP5 is the fifth phase of CMIP and was timed to provide important scientific input to the IPCC AR5 assessment (IPCC 2013).

damages far in the future). Additionally, Dietz et al. (2021a) found that for the long-term response (200 years after the pulse) FUND and DICE 2016 were higher than the FaIR emulations and the response of PAGE was consistently lower. (See Figure A.6.10 in the Appendix.)

As described in Section 2.3, all three of the approaches to damage function estimation in this report use only GMST as an input to the damage module. For the two more disaggregated approaches, GIVE and DSCIM, regional and higher resolution projections of climate variables were used internally to inform the shape of the global dose-response functions to GMST. That is, the functions relating damages to global temperature within GIVE and DSCIM damage modules are created using geographically disaggregated temperatures and precipitation data from GCMs and other sources, such as pattern scaling to fill out the distribution of possible local temperature and precipitation; once aggregated, GMST is the only input required to run the models.

*Figure 2.2.3: Global Mean Surface Temperature Anomaly from a Pulse of Carbon Dioxide (1GtC) by Model, 2020-2300*



*The mean global temperature response resulting from a pulse of emissions of CO<sub>2</sub> in 2030 as projected by FaIR1.6.2, Hector 2.5, and MAGICC 7.5.3. This represents the difference between a reference scenario (using SSP2-RCP4.5 for the figure) and the same scenario including the pulse of emissions. The emission pulse size is 1 GtC for carbon dioxide. Mean (solid) and median (dashed) lines are shown along with the 5<sup>th</sup> to 95<sup>th</sup> (dark shade) and 1<sup>st</sup> to 99<sup>th</sup> (light shade) percentile ranges.*

**Sea Level Rise.** In addition to temperature change, two of the three damage modules used in this report require global mean sea level (GMSL) projections as an input to estimate coastal damages. Those two

damage modules use different models for generating estimates of GMSL. Both are based off reduced complexity models that can use the FaIR temperature outputs as inputs to the model and generate projections of GMSL accounting for the contributions of thermal expansion and glacial and ice sheet melting based on recent scientific research. Absent clear evidence on a preferred model, the SC-GHG estimates presented in this report retain both methods used by the damage module developers.

The first damage module used in this report (discussed in Section 2.3.1) projects GMSL using an implementation of the Framework for Assessing Changes To Sea-level (FACTS). FACTS is a flexible computational framework, that can mix and match components of different models in order to further explore uncertainty that is being used for the IPCC AR6 SLR projections (IPCC 2021c, Garner et al. 2021).<sup>71</sup> In this damage module, FACTS is used to project sea level rise, relying on the parameterizations based on the two approaches that the IPCC characterized as “medium confidence”, and assuming that those two approaches were equally likely. This leads to a slightly narrower projected SLR range than the likelihood bounds from the IPCC medium confidence approach (given two distributions, the IPCC used the outermost probability for any given likelihood estimate). The choice of using only the medium confidence parameterizations leads to the lowest future sea level rise projections available from the FACTS model; the parameterization excludes the possible contributions from marine ice cliff instability (MICI) and from ocean forcing on basal melt rates that was also assessed to be low confidence by the IPCC.

The additional sea level rise resulting from the emissions pulse is estimated using what is known as a “semi-empirical”<sup>72</sup> sea level model (Kopp et al. 2016), which was cited by the National Academies as a potential approach for estimating SLR from an emissions pulse (National Academies 2017). The semi-empirical model is driven by the same probabilistic GMST projections from FaIR used in the non-coastal damages. It is calibrated based on historical data and has its own probability distribution that is generally lower than that seen in the FACTS projections. The FACTS projections account for a best understanding of future contributions to SLR from numerous sources but cannot be applied to an individual emissions pulse. Thus, to bias-correct the semi-empirical model’s projections, each probabilistic draw is quantile-mapped to an equivalent probabilistic draw of the FACTS projections within each SSP-RCP. The magnitude of the SLR impact of an emissions pulse is not changed, but the baseline SLR in the absence of the pulse is adjusted such that it is consistent with the probabilistic distribution from FACTS for each SSP-RCP. To model SLR in the RFF-SPs, for which no FACTS projections are available for bias correction, an additional quantile-mapping step is taken. This is detailed in CIL (2023).

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<sup>71</sup> Additional information about the IPCC AR6 SLR projection methods can be found at: [https://sealevel.nasa.gov/data\\_tools/17](https://sealevel.nasa.gov/data_tools/17).

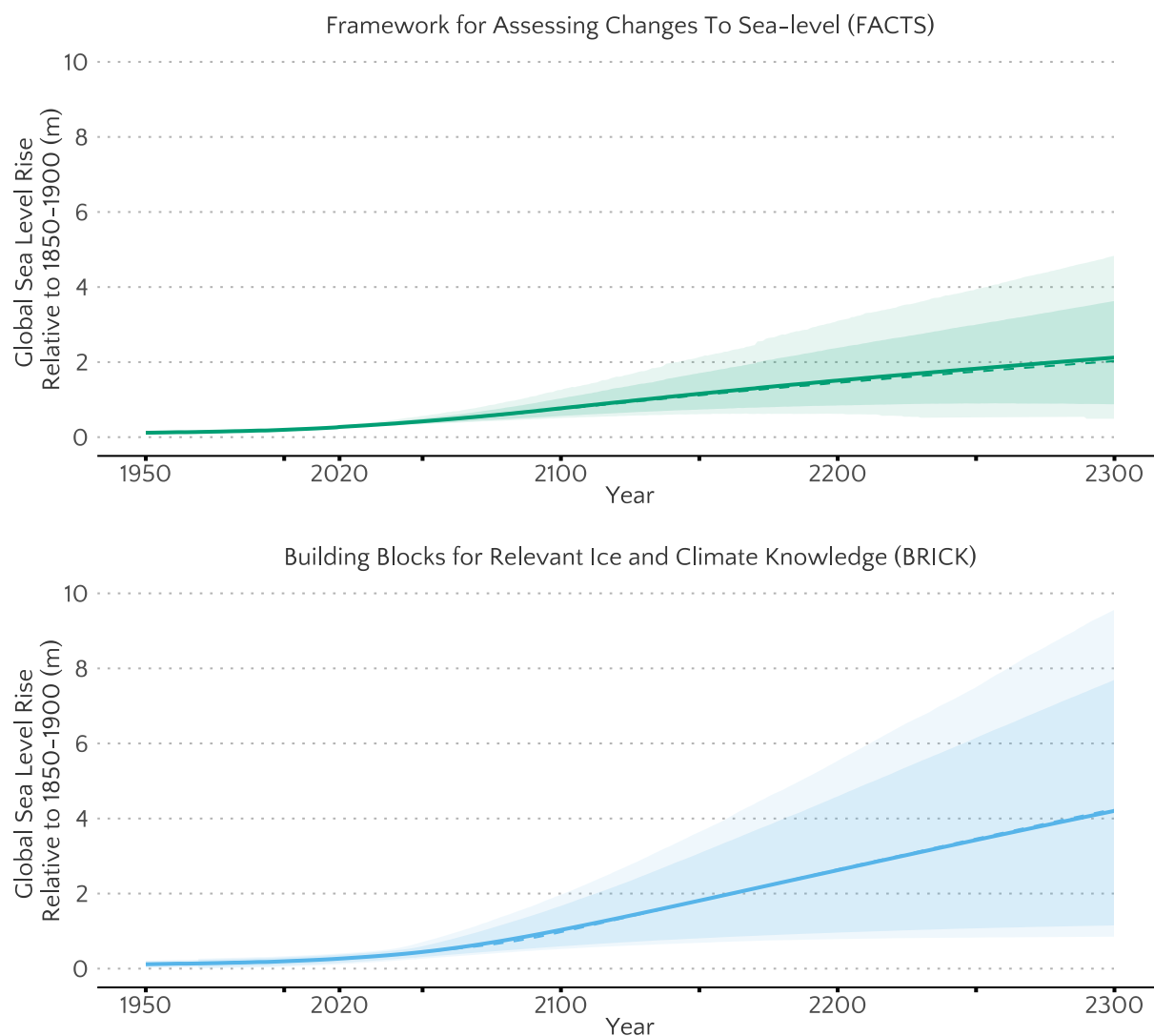
<sup>72</sup> Semi-empirical models are a form of reduced complexity process models. These models are known as semi-empirical because they are based on equations that embody physical understanding and calibrated to historical data. Semi-empirical models are a commonly used approach in the literature. The Kopp et al. (2016) model is based on a set of three differential equations: one to relate a change in sea level to a difference between projected atmospheric temperature and a theoretical equilibrium temperature, one to determine the change in the theoretical equilibrium temperature over time, and one to address the additional sea level rise from the climate response to long-term orbital changes. The parameters in these three equations are then calibrated against estimates of historical warming and sea level over the past millennia. The Kopp et al. (2016) model agreed well with process-based model and expert surveys available at the time. Semi-empirical models calibrated solely on historical data will not include processes that were not active over the historical calibration period, such as MICI processes (which are often not included in process-based models either).

The second SLR model used in this report, Building Blocks for Relevant Ice and Climate Knowledge (BRICK), is a semi-empirical modeling framework that simulates GMSL. Changes in global mean surface temperature drive changes in GMSL. The model includes contributions to GMSL from the Greenland and Antarctic ice sheets, thermal expansion, glaciers and ice caps, and land water storage (Wong et al. 2017, Vega-Westhoff et al. 2019). The parameterizations for the BRICK model include assumptions about Greenland and Antarctic melt that are consistent with the IPCC AR6 projections that include MICI. Inclusion of processes like MICI have the largest effects after 2100, and for the warmest scenarios, such that inclusion in the RCP8.5 scenario leads to an average increase of 15% in SLR by 2100 and 50% by 2150 (relative to 1850-1900, Table 9.10, IPCC 2021c). By 2300, inclusions of MICI processes for the RCP8.5 scenario results in SLR of 9.5 to 16.2 meters, which is substantially larger than the no ice-sheet acceleration assumption which yields a rise of 1.7 to 4.0 meters (Table 9.11, IPCC 2021c).

Figure 2.2.4 shows the projected global sea level change resulting from the FACTS- and BRICK-based SLR models, as implemented in the two damage modules discussed in Section 2.3. FACTS and BRICK have similar projections of SLR rise through the end of the century. BRICK, as expected, projects greater SLR in the out years because of its inclusion of accelerated melt processes for the Antarctic and Greenland ice sheet, consistent with the IPCC forecasts that include MICI processes. By 2300, BRICK estimates an average of 4 meters, while the implementation of FACTS used in this report generates SLR projections of 2 meters, on average. This difference in the out years is due to the choices of (a) relying only on IPCC's "medium confidence" SLR processes, and (b) taking an equal weighting rather than an outer envelope when combining multiple probability distributions. In the absence of a probabilistic assessment of the likelihood of these processes, this report retains use of both approaches.

In addition to surface temperatures and atmospheric concentrations, FaIR also calculates CO<sub>2</sub> uptake in the world's ocean as part of its carbon cycle calculation and generates projections of measures of ocean acidification (pH and ocean heat). The impacts of ocean acidification are not captured in the SC-GHG estimates presented in this report because functions that translate the pH and ocean heat outputs from FaIR into monetized global damages are not yet available in the damage module. However, given current understanding of the impacts of CO<sub>2</sub> emissions on the growth and survival of shellfish and coral reefs, coupled with the availability of market and nonmarket valuation studies on the ecosystem services they provide, it is likely feasible to develop damage functions that include ocean acidification impacts in future SC-GHG updates. See section 3.2 for more discussion of damages associated with ocean acidification and other impacts of climate change that are not captured in this report.

Figure 2.2.4: Global Sea Level Rise in FACTS and BRICK, 1950-2300



The range of global mean sea level rise relative to pre-industrial (1850-1900) as calculated by Framework for Assessing Changes To Sea-level (FACTS) (top) and Building Blocks for Relevant Ice and Climate Knowledge (BRICK) (bottom). Uncertainty comes from emissions uncertainty from the RFF-SP projections, physical climate uncertainty from FaIR, and parameter uncertainty underlying each SLR module. Mean (solid) and median (dashed) lines are shown along with the 5<sup>th</sup> to 95<sup>th</sup> (dark shade) and 1<sup>st</sup> to 99<sup>th</sup> (light shade) percentile ranges.



## 2.3 Damage Module

The damage module contains the core “damage functions” in the SC-GHG estimation process. Damage functions translate changes in temperature and other physical impacts of climate change into monetized estimates of net economic damages. The damage functions capture multiple net damage pathways that can be broadly divided into market and non-market pathways. Some net economic damages are experienced through markets, such as changes in net agricultural productivity, net energy expenditures, and property damage from increased flood risk. Examples of net damages experienced through the nonmarket pathways include changes in net mortality rates and changes in ecosystem services, including those provided by biodiversity.

As discussed above, the SC-GHG estimates used in the EPA’s analyses to date have maintained the damage functions contained in the default version of the DICE, FUND, and PAGE IAMs as used in the peer-reviewed literature. Specifically, the damages functions underlying the IWG SC-GHG estimates used since 2013 are taken from DICE 2010 (Nordhaus 2010); FUND 3.8 (Anthoff and Tol 2013a, 2013b); and PAGE 2009 (Hope 2013).<sup>73</sup> These models all take stylized, reduced-form approaches to estimating monetized damages as a function of temperature change and sea level rise. They use a suite of underlying studies to calibrate their damage functions. FUND 3.8 takes a regional bottom-up approach to specify the damage function by calibrating to or building up disaggregated pieces consisting of 14 separate damage categories using studies and assumptions relating to each category. Damages in DICE 2010 are an aggregate based on a calibration of sectoral damages (Nordhaus and Boyer 2000) and scaled using aggregate damages. PAGE 2009 employs a regionalized hybrid approach with an estimate of four categories of damages: economic, sea level rise, nonmarket, and “discontinuities” (nonlinear extreme events<sup>74</sup>).

The National Academies’ recommendations for the damage module, scientific literature on climate damages, updates to models that have been developed since 2010, as well as the public comments received on individual EPA rulemakings and the IWG’s February 2021 TSD, have all helped to identify available sources of improved damage functions. The IWG (e.g., IWG 2010, 2016a, 2021), the National Academies (2017), comprehensive studies (e.g., Rose et al. 2014), and public comments have all recognized that DICE 2010, FUND 3.8, and PAGE 2009 do not include all the important physical, ecological, and economic impacts of climate change. The climate change literature and the science underlying the

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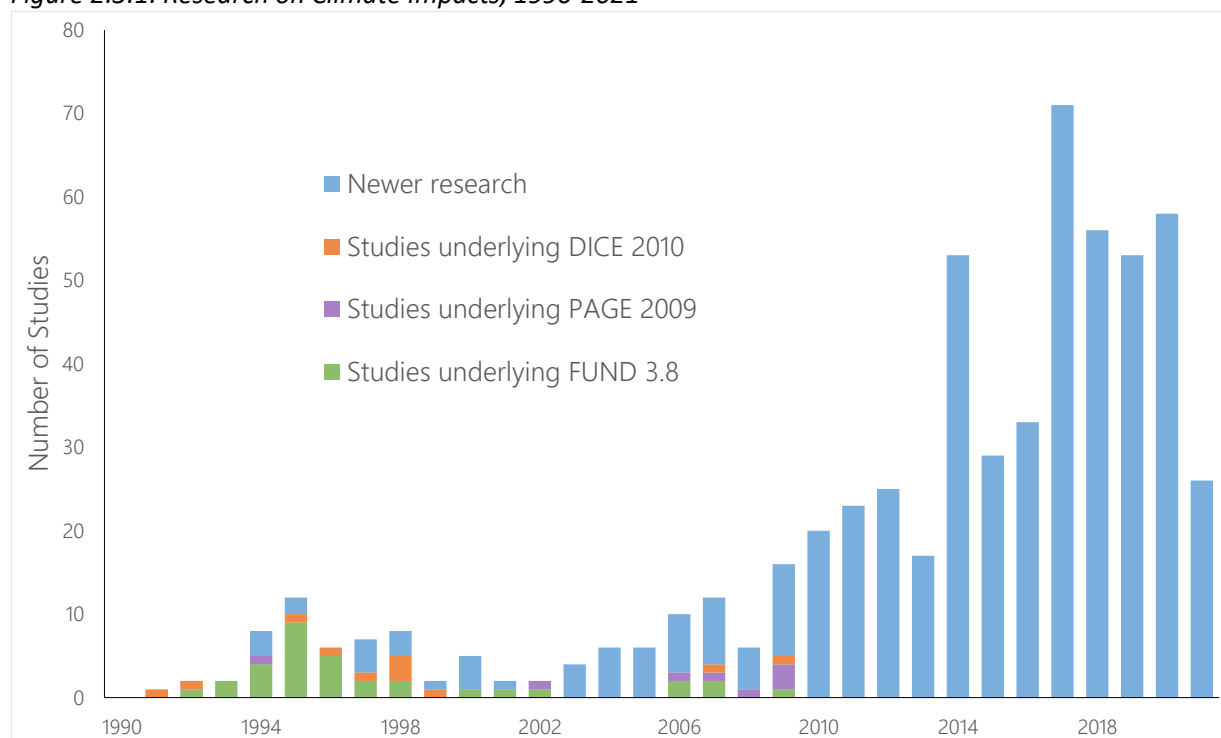
<sup>73</sup> The damages functions underlying the IWG SC-GHG estimates used from 2010 to 2013 came from earlier versions of each model: DICE 2007 (Nordhaus 2008), FUND 3.5 (Narita et al. 2010), and PAGE 2002 (Hope 2006). The newer versions of each model that have been used by the IWG since 2013 included a number of updates related to their damage functions. For example, DICE 2010 included a re-calibrated damage function with an explicit representation of economic damages from sea level rise. Updates in FUND 3.8 included revised damage functions for space heating, SLR, and agricultural impacts. PAGE 2009 added an explicit representation of SLR damages, revisions to ensure damages do not exceed 100% of GDP, a change in regional scaling of damages, revised treatment of potential abrupt damages, and updated adaptation assumptions. See IWG (2013) for more discussion of each of these changes.

<sup>74</sup> Additional damages from an extreme event, such as extreme melting of the Greenland ice sheet, were multiplied by the probability of the event occurring and added to the damage estimate. In PAGE 2009, a large-scale discontinuity becomes possible when the temperature rises beyond some threshold value between 2 and 4°C. The model assumes that only one discontinuity can occur and that the impact is phased in over a period of time, but once it occurs, its effect is permanent. See IWG (2016a) for more discussion.

economic damage functions have evolved, and DICE 2010, FUND 3.8, and PAGE 2009 now lag behind the most recent research.

The challenges involved with updating damage functions have been widely recognized. Functional forms and calibrations are constrained by the available literature and need to extrapolate beyond warming levels or locations studied in that literature. Research and public resources focused on understanding how these physical changes translate into economic impacts have been significantly less than the resources focused on modeling and improving our understanding of climate system dynamics and the physical impacts from climate change (Auffhammer 2018). Even so, as illustrated in Figure 2.3.1, there has been a large increase in research on climate impacts and damages in the time since DICE 2010, FUND 3.8, and PAGE 2009 were published. There continues to be wide variation in methodologies and scope of studies, such that care is required when synthesizing the current understanding of impacts or damages.

Figure 2.3.1: Research on Climate Impacts, 1990-2021<sup>75</sup>



Source: Greenstone (2016), updated in 2021.

Approaches to developing a damage module for SC-GHG estimation can be generally grouped into two broad categories: those that estimate a damage function by calibrating to or building up disaggregated

<sup>75</sup> In many cases, the three IAMs used different studies for calibration. This is particularly true of FUND, which used studies relating to different subsectors of the model, whereas DICE and PAGE did not have as detailed a sectoral breakdown. That means that summing across these different models is likely valid in all but a few isolated cases. The blue bars include studies uncovered from a comprehensive literature review in the economics literature (and a few others in public health or relevant disciplines) by the Climate Impact Lab through early 2016. Each of the studies counted in blue was determined by CIL to have employed a research design that allowed for the causal interpretation of results (Greenstone 2016).

pieces, and studies that estimate an aggregate global damage function directly. The more disaggregated approach typically involves spatially explicit and sectoral or category-specific modeling of relevant processes and then aggregates regional or sectoral damages.<sup>76</sup> Alternatively, the aggregate global damage function estimation approach often relies on meta-analysis techniques (e.g., as in recent versions of DICE (DICE 2013R and DICE 2016)) or total-economy empirical studies that econometrically estimate the relationship between GDP and a climate variable, usually temperature (e.g., used in part in the most recent version of the PAGE model (PAGE 2020 (Kikstra et al. 2021))). There are also more complex ways to estimate damage functions directly (e.g., that have been used in extensions of DICE) and through expert elicitation (e.g., Pindyck 2019, Howard and Sylvan 2021). Based on a review of available studies using these approaches, the SC-GHG estimates presented in this report rely on three damage functions. They are:

1. a subnational-scale, sectoral damage function estimation (based on the Data-driven Spatial Climate Impact Model (DSCIM) developed by the Climate Impact Lab (CIL 2023, Carleton et al. 2022, Rode et al. 2021)),
2. a country-scale, sectoral damage function estimation (based on the Greenhouse Gas Impact Value Estimator (GIVE) model developed under RFF's Social Cost of Carbon Initiative (Rennert et al. 2022b), and
3. a meta-analysis-based global damage function estimation (based on Howard and Sterner (2017)).

Each is discussed in turn.

### **2.3.1 Damage Module based on the Data-driven Spatial Climate Impact Model (DSCIM)**

DSCIM was developed by the Climate Impact Lab (CIL). CIL is a multidisciplinary consortium of climate scientists, economists, computational experts, researchers, and analysts building empirically derived, local-level estimates of the net damages from climate change and empirically based SC-GHG estimates.<sup>77</sup> The DSCIM modeling runs performed for the estimates presented in this report are described in the September 2023 DSCIM User Manual (CIL 2023). DSCIM monetizes climate damages for nearly 25,000 global impact regions using econometric methods that account for local conditions, including adaptation investments, when estimating the effect of climate change on sector specific outcomes. These local damages are aggregated to develop an estimate of global damages as a function of global temperature changes. The damage functions for DSCIM are constructed through a five-step process. First, researchers collect and harmonize historic climate and socioeconomic data for each sector. Second, using variation in

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<sup>76</sup> Consistent with the terminology used by the National Academies (2017) and many researchers in the academic literature on the SC-GHG, in this report “sector” is generally used to refer to climate impact categories, rather than specific industry sectors (e.g., agriculture, manufacturing, construction) of the economy. In the relatively few studies that rely on multisectoral, multiregional economic computable general equilibrium (CGE) models to build damage functions, the term may be used in the more traditional way to refer to economic sectors. CGE models calibrate to region-sector impact estimates but account for more interactions among regions, impacts, supply, and demand factors.

<sup>77</sup> The Climate Impact Lab team combines experts from the University of California, Berkeley, the Energy Policy Institute at the University of Chicago (EPIC), Rhodium Group, Rutgers University, University of California, Santa Barbara, and University of Delaware. More information on the individual researchers and institutions involved in the Climate Impact Lab can be found at: <http://www.impactlab.org/>.

short-run weather and cross-sectional variation in the long-run average climate and socioeconomic conditions, they econometrically estimate the effect of changes in local climatic conditions on sector-specific outcomes, accounting for the adaptive effects of climate and socioeconomics, which can alter the sensitivity of outcomes to local climate. Third, they use a revealed preference approach to infer the adaptation costs incurred by populations as they adapt to warming, drawing on research by Guo and Costello (2013) and Deryugina and Hsiang (2017).<sup>78</sup> Fourth, they project sector-specific outcomes and associated monetized damages into the future by combining the econometric results with a probabilistic ensemble of high-resolution downscaled climate projections from 33 global climate models<sup>79</sup> and aggregate the local damages to global damages. Finally, they use these projections to estimate global damages as a time-varying reduced-form function of global mean surface temperature. The advantage to this approach is that global damage estimates reflect the empirically derived local impact relationships, and account for the uncertainty in economic growth, temperature change, and adaptation. For the DSCIM model runs in this report, the outputs of the socioeconomic module (Section 2.1) and the GMST output from the climate module (Section 2.2) are used as inputs in DSCIM.<sup>80</sup>

At present, DSCIM includes the estimation of climate damages occurring in five impact categories: health, energy, labor productivity, agriculture, and coastal regions (CIL 2023).<sup>81</sup> Table 2.3.1 summarizes key elements of DSCIM's damage function estimation methods in each of these five categories. The health component includes the value of net changes in hot- and cold-related mortality risk (Carleton et al. 2022). The building block of the global mortality damage function is the estimation of temperature's impact on mortality rates using historical data. The mortality data is assembled from various sources at the subnational spatial scale<sup>82</sup> for 40 countries covering 38% of the global population.<sup>83</sup> Temporal coverage for each country ranges from 13 years (1997-2010) to over 40 years (e.g., 1968-2010 for the U.S.) across the sample. The age-specific mortality-temperature response is estimated as a linear function of nonlinear

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<sup>78</sup> The method for estimating the costs of adaptation reflects that people invest in adaptive behaviors and technologies until the costs of doing so just equal the protective benefits. The protective benefits are observed through the changes in the estimated sensitivity of outcomes to temperature (or rainfall or sea level rise) as the climate gradually warms. The estimated measures of these benefits are used to back out the costs of the adaptation. See Carleton et al. (2022) for more discussion.

<sup>79</sup> See CIL (2023) for a detailed discussion of the ensemble of climate projections.

<sup>80</sup> To incorporate the RFF-SPs for model runs performed for this report, DSCIM uses an emulator approach that allows for the use of probabilistic socioeconomics in DSCIM's highly complex and disaggregated damage system. The emulator weights the outcome of annual global aggregate damage functions, that are estimated using the suite of SSP-RCP combinations, according to how closely the socioeconomics characteristics each year match those contained in the RFF-SPs. See CIL (2023) for more details. The use of this emulator approach is an approximation to modeling large numbers of probabilistic scenarios directly, which was not feasible in DSCIM's computationally intensive and high spatial resolution environment and offers an additional source of methodological uncertainty in the DSCIM-based results presented in this report.

<sup>81</sup> CIL plans to update DSCIM regularly with representation of additional sectors (CIL 2023).

<sup>82</sup> The mortality data is at the second administrative level (e.g., county), first administrative level (e.g., state), or somewhere in between.

<sup>83</sup> Carleton et al. (2022) also have data from India (which increases coverage to 55% of the global population) but are unable to include it in the main estimation of the mortality-temperature response function due to the absence of age-specific mortality statistics. Instead, the authors use the India data to assess external validity of their extrapolation methods and find the model "generates conservative predictions of mortality impacts of climate change in India, a hot and poor region of the globe" (p. 26).

daily grid-level temperature and precipitation data transformations. This specification, together with the inclusion of fixed effects to account for any time-varying trends or shocks to age-specific mortality rates unrelated to climate, allows them to isolate the impact of year-to-year, within-location variation in temperature and rainfall on mortality. Additionally, this model recovers the effect of climate-driven adaptation (e.g., more cooling systems) and income growth on the shape of the temperature mortality relationship, as observed in the historical record using cross-sectional variation in long-run average conditions. These econometric estimates are combined with high-resolution projections of climate, income, and demographics to compute age-specific projected impacts of climate change under multiple emissions scenarios at the scale of ~25,000 global regions. While the main specification of DSCIM employs an age-adjusted valuation approach for monetizing net health damages (inclusive of adaptation costs), in the results presented in this report, the projected changes in premature mortality are monetized using country-level population-average measures of the willingness-to-pay for mortality risk reductions.<sup>84</sup>

The energy component includes energy expenditures from temperature-related changes in electricity and direct fuel consumption across residential, commercial, and industrial end-uses (Rode et al. 2021). Rode et al. provide the first estimate of the global impact of climate change on total energy consumption using globally comprehensive data, accounting for economic development and adaptive behavior. Energy consumption data for electricity and other fuels is compiled from the International Energy Agency and is available at the country-by-year level for 146 countries from 1971 to 2010. Daily historical climate data are aggregated to annual, country-level observations following the method in Carleton et al. (2022), which preserves local-level nonlinearities in the relationship between energy consumption and temperature. Modeled energy responses to temperature changes reflect income changes and climate adaptation (e.g., installation of air conditioning in areas that currently have little penetration and more frequent operation of existing air conditioning equipment). Similar to Carleton et al., the modeled energy-temperature relationship for a local impact region is a function of conditions at that location. This allows the authors to compute the additional impact of climate change on energy consumption, net of local factors (e.g., income) that will change in the future. Using the same income and climate projections as in Carleton et al. (2022), Rode et al. compute projected impacts of climate change on electricity and other fuels consumption under multiple emissions scenarios at the scale of ~25,000 global regions.<sup>85</sup> To value these impacts, the results presented in this report use country-level energy prices from the International Energy Agency's (IEA) *World Energy Outlook* (IEA 2017) and *Energy Prices and Taxes* (IEA 2018) dataset. Prices are

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<sup>84</sup> Specifically, projected changes in premature mortality in the U.S. are monetized using the same value of mortality risk reduction as in the EPA's regulatory analyses (\$4.8 million in 1990 (1990USD)) and adjusted for income growth and inflation following current EPA guidelines and practice (EPA 2010) and consistent with EPA Science Advisory Board (SAB) advice (see e.g., EPA 2011, OMB 2003), resulting in a 2020 value of \$10.05 million (2020USD). Valuation of mortality risk changes outside the U.S. is based on an extrapolation of the EPA value that equalizes willingness-to-pay as a percentage of per capita income across all countries (i.e., using an assumed income elasticity of 1). The use of a benefits transfer approach based on a positive income elasticity is consistent with the approach used in the default version of the models and published studies used in this report (e.g., Rennert et al. 2022b, Carleton et al. 2022, Diaz 2016), and other academic literature. See Appendix A.7 for more discussion.

<sup>85</sup> Additional energy consumption from temperature-related changes is a defensive expenditure for climate change impacts. Bartik (1988) shows that defensive expenditures of this sort are a lower bound of the compensating surplus associated with a reduction in environmental quality. As such, the estimate of monetized net damages in this sector are a lower bound on the theoretically correct welfare impact.

extrapolated into the future based on the growth rates projected in the U.S. Energy Information Administration's *Annual Energy Outlook 2021* (EIA 2021). Specifically, based on the AEO projections, prices are assumed to grow at an annual rate of -0.27% and 0.82% for electricity and other fuels, respectively. See CIL (2023) for more discussion.

The labor productivity component of the model captures the value of labor losses, as measured in labor disutility, from responses in daily temperature (Rode et al. 2022). Evidence shows that workers in industries such as agriculture, construction, manufacturing, transport, and utilities reduce their hours worked when outdoor temperatures deviate from average temperatures.<sup>86</sup> Daily variation in weather for seven countries representing about 30% of the global population is used to econometrically estimate subnational labor supply responses to temperature changes. The labor response is estimated to be an inverted U-shaped relationship, with lost labor occurring at extreme hot and cold temperatures, for high-risk, weather-exposed sectors and low-risk sectors. The labor supply temperature response is projected globally and over time, following Carleton et al. (2022) and Rode et al. (2021). It includes predicted shifts towards less weather-exposed industries as a function of average income per capita and long-run average temperature, analogous to other forms of adaptation accounted for in Carleton et al. (2022) and Rode et al (2021). The value of lost productivity is monetized as the compensating wage increase needed to offset the temperature change's disutility.

DSCIM captures the net production impact of climate change in the agriculture sector by computing projected impacts for six globally and regionally important staple crops that represent two thirds of global crop caloric production: maize, wheat, rice, soybean, sorghum, and cassava (Hultgren et al. 2022). The DSCIM reduced-form econometric approach simultaneously captures the combined impact of biophysical crop responses and producer decision-making to account for the costs, benefits, and adoption rates of producer adaptations as they are observed in practice around the world. This contrasts with prior analyses that rely on agronomic process-based models to explicitly characterize the biophysical processes to project yields. DSCIM accounts for several types of adaptation. First, the model allows for within-crop adaptations such as varietal switching and other changes in production methods, such as irrigation, fertilization, and planting dates. Second, in the monetization step, the results are multiplied by 0.45 to account for crop switching and trade protective effects, from frictionless trade within continents and global trade networks, based on an average of the estimates in prior research documenting these quantities (e.g., Rising and Devineni 2020; Costinot et al. 2016; Gouel and Laborde 2021; Stefanović et al. 2016). The DSCIM results presented in this report also account for the fertilization benefits of CO<sub>2</sub> emissions on crop yields based on established estimates in the literature (Moore et al. 2017).

Finally, the coastal component of DSCIM estimates damages resulting from sea level rise inundation in coastal regions. As described in Section 2.2, the GMSL projections are based on the probabilistic FACTS model that is being used in IPCC's AR6 report (Kopp et al. 2016, Garner et al. 2021). To generate a damage function relating GMSL to welfare loss, probabilistic local mean sea level (LMSL) projections are used as inputs to an updated version (Depsky et al. 2023) of the Coastal Impact and Adaptation Model (CIAM) (Diaz 2016). These projections come from LocalizeSL (Kopp et al. 2017), using AR5 emissions trajectories. The updated CIAM model (pyCIAM) estimates highly localized SLR related damages (Diaz 2016). CIAM is a

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<sup>86</sup> See Rode et al. (2021) for a listing of literature across many disciplines that have studied the effects of temperature on worker performance and labor, dating back to Huntington (1922).

deterministic optimization model that chooses the least-cost adaptation strategy for each of the 9,000 coastal segments defined in the Sea Level Impacts Input Dataset by Elevation, Region, and Scenario (SLIIDERS, Depsky et al. 2023)<sup>87</sup> after accounting for local physical and socioeconomic characteristics.<sup>88</sup> Damages are then estimated as the costs associated with the selected adaptation strategy plus the residual damages due to inundation, wetland loss, and flooding.

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<sup>87</sup> The SLIIDERS dataset provides details on local physical and socioeconomic characteristics. The original CIAM uses 12,148 coastal segments in the Dynamic Interactive Vulnerability Assessment (DIVA) database. The use of 9,000 segments in DSCIM is just the result of Depsky et al. (2023)'s re-optimization of the coastal segment choices (e.g., in the original CIAM inputs, 10% of the 12,000 global segments were in French Polynesia).

<sup>88</sup> In CIAM the adaptation choice set includes ten total adaptation strategy options. Each strategy is a combination of an adaptation option and, in cases of taking adaptive measures, a discrete level. The three adaptation options are (1) retreating inland from the coastline, (2) protecting coastal communities and infrastructure, or (3) taking no adaptive measures. The protection option has four available levels, corresponding to 10, 100, 1000, and 10000-year maximum storm surge height. The retreat option has the same available levels as protection, in addition to a minimum level corresponding to the mean sea level rise. The decision maker first selects the lowest-cost combination of these across the full model horizon, and then chooses the degree of investment in coastal defense against several different return periods, under the assumption of perfect foresight about SLR conditions. See Section 3.2 for related details on modeling assumptions and limitations.

*Table 2.3.1: Current Coverage of Climate Damages in DSCIM*

| Impact Category    | Damage Components Represented                                                                                                                | Empirical Basis for Damage Function Estimation                                                                                                                                                   | Accounting for Adaptation                                                                                                                                                                  | Documentation                                                                                         |
|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|
| Health             | Heat- and cold-related mortality                                                                                                             | Subnational annual mortality statistics for 40 countries covering 38% of global population; 1990-2010 or longer for most countries                                                               | Accounts for adaptative effects of income growth and estimates the costs of adaptive investments using a revealed preference approach                                                      | Carleton et al. (2022)                                                                                |
| Energy             | Expenditures for electricity and other direct fuel consumption                                                                               | Annual country-level energy consumption data (residential, commercial, and industrial) by energy source for 146 countries, 1971-2010                                                             | Accounts for both climate- and socioeconomics-driven adaptive responses                                                                                                                    | Rode et al. (2021)                                                                                    |
| Labor Productivity | Labor disutility costs from labor supply responses to increased temperature                                                                  | Daily worker-level labor supply data (minutes worked) from 7 countries representing nearly 30% of global population                                                                              | Accounts for shifts in workforce composition to less weather-exposed industries                                                                                                            | Rode et al. (2022)                                                                                    |
| Agriculture        | Production impacts for six crops: maize, rice, wheat, soybeans, sorghum, and cassava                                                         | Subnational crop production data for over 12,658 sub-national administrative units from 55 countries                                                                                             | Accounts for CO <sub>2</sub> fertilization effects, varietal switching, changes in production methods (e.g., irrigation, fertilization, planting dates), crop switching, and trade effects | Hultgren et al. (2022)                                                                                |
| Coastal regions    | Impacts of SLR as realized through inundation, migration, protection, dry and wetland loss, and mortality and physical capital loss from SLR | Numerous empirical findings are used to parameterize the CIAM process model for 9,000 coastal segments. (Low levels of SLR in the historical record prohibit the use of a fully empirical model) | Reflects retreat or protective infrastructure and costs under an optimal adaptation scenario with perfect foresight of SLR                                                                 | Kopp et al. (2016) and Garner et al. (2021) for SLR; Diaz (2016) and Depsky et al. (2023) for damages |

### 2.3.2 Damage Module Based on the Greenhouse Gas Impact Value Estimator (GIVE)

The second damage module used in this report is taken from the GIVE integrated assessment model (IAM). GIVE is an open-source IAM developed under the Resources for the Future Social Cost of Carbon Initiative in collaboration with dozens of researchers from private and public institutions across the globe, spanning a wide range of disciplines (Rennert et al. 2022b). The model was developed in direct response to the National Academies (2017) recommendations surrounding needed improvements in the estimation of the



SC-GHG. The damage function component of the model is structured in such a way that it can accommodate additional damage categories underlying the estimation of the SC-GHG, making it particularly attractive for incorporating future research and findings.<sup>89</sup> Moreover, the model can accommodate components with differing temporal and spatial resolutions. The model can be estimated deterministically (fixed parameter) or in a Monte Carlo (random parameter) setting, sampling from socioeconomic, climate, and damage function distributions to allow for uncertainty within and across each of its components. In the model runs performed for this report, the outputs of the socioeconomic module and the GMST projections from the climate module described above serve as inputs to the damage function components of GIVE.

At present, GIVE includes estimation of climate damages occurring in four sectors or impact categories: health, energy, agriculture, and coastal regions.<sup>90</sup> The damage functions reflect recent scientific advancements in the peer-reviewed literature. Table 2.3.2 summarizes key elements of GIVE's damage function estimation methods in each of these four categories. The health damage function is based on a recent study authored by a collaboration of public health, epidemiology, climatology, and economics experts in response to the 2017 National Academies' recommendations (Cromar et al. 2022). The authors, along with an additional panel of convening experts, conducted a systematic review and meta-analysis of health impacts related to climate change. Then, regionally resolved all-cause mortality estimates from increases in temperature were generated through a random-effects pooling of studies that were identified in the systematic review.<sup>91</sup> Net changes in mortality risk associated with increased average annual temperatures were estimated for all global regions varying in their effect size and uncertainty across each of the 9 regions. The resulting changes in premature mortality are mapped to country-specific baseline mortality projections and rates such that premature mortality from global climate change is unique to all 184 countries. Uncertainty in the mortality damage function is parametric and sampled from the region-specific coefficient that relates GMST to changes in premature mortality. The GIVE model monetizes the projected changes in premature mortality using country-level population-average measures of the willingness-to-pay for mortality risk reduction (Rennert et al. 2022b), consistent with methodology used in the DSCIM model runs presented in this report and described above.

The energy damage function component of GIVE is based on a recent multidisciplinary study that estimates the relationship between changes in building energy expenditure (net heating and cooling expenses) and changes in local temperature and climate (Clarke et al. 2018). That study used the Global Change Analysis Model (GCAM) that models regional changes in heating and cooling expenditures as a proportion of regional gross domestic product resulting from changes in regional temperatures. That is, for each of the 12 GCAM regions, Clarke et al. (2018) find an approximately linear relationship between degrees of temperature change and net change in energy expenditures. Reflecting this, the climate-

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<sup>89</sup> The GIVE model is built on the Mimi.jl platform, an open-source package for constructing modular integrated assessment models, [www.mimiframework.org](http://www.mimiframework.org). GIVE is written using the Julia programming language which allows for extremely fast estimation times.

<sup>90</sup> The modular nature of GIVE offers a straightforward way to add other damage functions and sectors. For example, nonuse biodiversity losses are currently under development based on an approximation of studies such as Brooks and Newbold (2014) (Official communication with GIVE model developers, 2023).

<sup>91</sup> A total of 33 unique health studies, most of which were extensive multi-locational studies, were included in Cromar et al. (2022). Studies were predominately from North America, Europe, and East Asia and thus some of the more populous parts of the world were underrepresented (Cromar et al. 2022).

expenditure relationship from Clarke et al. (2018) is estimated within GIVE by a regional linear regression that yields region-specific damage functions to estimate changes in net energy expenditures within each of the 184 countries in the model.

The agriculture damage function component of GIVE follows Moore et al. (2017). It is derived using (1) a meta-analysis of over 1,000 published temperature-yield response estimates from 55 unique studies, and (2) an open-source computable general equilibrium (CGE) model that estimates the welfare consequences (as equivalent variation) of climate-induced productivity changes, accounting for adjustments in agricultural markets including trade patterns, consumption, and production. The productivity changes (for maize, rice, wheat, and soybeans) are based on biophysical crop impacts documented in the literature. Productivity impacts include both within-crop adaptations (e.g., varietal and planting date changes) as well as CO<sub>2</sub> fertilization using estimates of the size of these effects from the meta-analysis. Welfare changes at 1, 2 and 3 degrees of warming calculated from the CGE model give damage functions for 140 regions. GIVE maps the regions to all 184 countries for country-level effects on crop production. Within GIVE, the non-parametric uncertainty provided in Moore et al. (2017) is converted to parametric damage uncertainty and used in the Monte Carlo estimation.

The fourth damage component in GIVE connects the BRICK sea level rise (SLR) model (Wong et al. 2017) and the CIAM model (Diaz 2016) to estimate SLR induced coastal damages from temperature change. As described in Section 2.2, GMST and ocean heat content from FaIR 1.6.2 are used as inputs to BRICK to generate projections of GMSL. As in the damage module described above based on DSCIM, the GMSL projections are downscaled to a 1-degree grid (Slangen et al. 2014) and used as inputs to CIAM to estimate local adaptation decisions and their associated costs.<sup>92</sup> Since CIAM is a deterministic model, uncertainty in coastal damages is the result of uncertainty in BRICK that arises due to the RFF-SP probabilistic emission scenarios and sampled climate and sea level parametric uncertainty.

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<sup>92</sup> As noted in Section 2.3.1, CIAM includes 12,148 unique coastal segments. Of these 11,835 correspond to countries included in the GIVE model. See Rennert et al. (2022b) for a full description.

*Table 2.3.2: Current Coverage of Climate Damages in GIVE*

| Impact Category | Damage Components Represented                                                                                                                | Empirical Basis/Methodology                                                                                           | Accounting for Adaptation                                                                                                                                                                                                                    | Documentation                                       |
|-----------------|----------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------|
| Health          | Heat- and cold-related mortality risk                                                                                                        | Pooled effect estimates (36 studies across 9 regions) for changes in temperature on mortality risk, by region         | Observed responses to changes in temperature are assumed to persist into the future                                                                                                                                                          | Cromar et al. (2022)                                |
| Energy          | Expenditures for space heating and cooling in buildings                                                                                      | Regional costs of energy consumption, temperature, and climate                                                        | Implicit in the regional relationship between increases in energy expenditures and temperature                                                                                                                                               | Clarke et al. (2018)                                |
| Agriculture     | Welfare changes from temperature driven changes in production of four crops: maize, rice wheat, and soybeans                                 | Meta-analysis of 1,010 yield effect estimates from 55 studies and computable general equilibrium (CGE) model of trade | Explicit in the estimation of the damage function through assumed changes in on-farm, within-crop, management practices. Adaptive adjustments in agricultural markets through changes in crops, trade, consumption, and production patterns. | Moore et al. (2017)                                 |
| Coastal regions | Impacts of SLR as realized through inundation, migration, protection, dry and wetland loss, and mortality and physical capital loss from SLR | Numerous empirical findings are used to parameterize the CIAM process model for 11,835 coastal segments               | Reflects retreat or protective infrastructure and costs under an optimal adaptation scenario with perfect foresight of SLR                                                                                                                   | Wong et al. (2017) for SLR; Diaz (2016) for damages |

The damage functions in DSCIM and GIVE represent substantial improvements relative to the damage functions underlying the SC-GHG estimates used by the EPA to date in reflecting the forefront of scientific understanding about how temperature change and SLR lead to monetized net (market and nonmarket) damages for several categories of climate impacts. The models' spatially explicit and impact-specific modeling of relevant processes allows for improved understanding and transparency about mechanisms through which climate impacts are occurring and how each damage component contributes to the overall results, consistent with the National Academies' recommendations. DSCIM addresses common criticisms related to the damage functions underlying current SC-GHG estimates (e.g., Pindyck 2017) by developing multi-sector, empirically grounded damage functions.<sup>93</sup> The damage functions in the GIVE model offer a direct implementation of the National Academies' near-term recommendation to develop updated sectoral damage functions that are based on recently published work and reflective of the current state of knowledge about damages in each sector. Specifically, the National Academies noted that "[t]he literature on agriculture, mortality, coastal damages, and energy demand provide immediate

<sup>93</sup> Note that Pindyck has consistently noted that modeling and damage category considerations are not a reason to abandon the social cost of greenhouse gases; Pindyck has consistently supported updating the IWG's past estimates (Pindyck 2013, 2017, 2019, 2021).

opportunities to update the [models]” (National Academies 2017, p. 199), which are the four damage categories currently in GIVE. A limitation of both models is that the sectoral coverage is still limited, and even the categories that are represented are incomplete. For example, the coastal damage estimates in both models do not fully reflect the consequences of SLR-driven salt-water intrusion and erosion, or SLR damages to coastal tourism and recreation. In addition, neither DSCIM nor GIVE yet accommodate estimation of other categories of temperature driven climate impacts (e.g., morbidity, conflict, migration, biodiversity loss) and only a limited subset of damages from changes in precipitation (e.g., while precipitation is considered in the agriculture sectors in both DSCIM and GIVE, neither model takes into account impacts of flooding, changes in rainfall from tropical storms, and other precipitation related impacts). Other missing elements are damages that result from other physical impacts (e.g., ocean acidification, non-temperature-related mortality such as diarrheal disease and malaria) and the many feedbacks and interactions across sectors and regions that can lead to additional damages.<sup>94,95</sup> See Section 3.2 for more discussion of omitted damage categories and other modeling limitations. DSCIM and GIVE do account for the most commonly cited benefits associated with CO<sub>2</sub> emissions and climate change – CO<sub>2</sub> crop fertilization and declines in cold related mortality. As such, while the GIVE- and DSCIM-based results presented in this report provide state-of-the-science assessments of key climate change impacts, they remain partial estimates of future climate damages resulting from incremental changes in CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O. One advantage of the modular approach used by these models is that future research on new or alternative damage functions can be incorporated in a relatively straightforward way. DSCIM and GIVE developers have work underway on other impact categories that may be ready for consideration in future updates (e.g., morbidity and biodiversity loss).

### 2.3.3 Damage Module Based on a Meta-Analysis Approach

Given the still relatively narrow sectoral scope of the recently developed DSCIM and GIVE models, this report includes a third damage function that reflects a synthesis of the state of knowledge in other published climate damages literature. Studies that employ meta-analytic techniques<sup>96</sup> offer a tractable and straightforward way to combine the results of multiple studies into a single damage function that represents the body of evidence on climate damages that pre-date CIL and RFF’s research initiatives.

Meta-analysis is a common tool in empirical research. Within the climate change literature, meta-analyses have been used to analyze physical and sector impacts (e.g., Moore et al. 2017, Hoffmann et al. 2020, Cromar et al. 2022) and to directly estimate aggregate global damage functions. The first use of meta-analysis to combine multiple climate damage studies was done by Tol (2009) and included 14 studies. The studies in Tol (2009) served as the basis for the global damage function in DICE starting in version 2013R (Nordhaus 2014). The damage function in the most recent published version of DICE, DICE 2016, is from an updated meta-analysis based on a rereview of existing damage studies and included 26 studies

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<sup>94</sup> The one exception is that the agricultural damage function in DSCIM and GIVE reflects the ways that trade can help mitigate damages arising from crop yield impacts.

<sup>95</sup> See Section 3.2 for more discussion of omitted categories of climate impacts and associated damages.

<sup>96</sup> Meta-analysis is a statistical method of pooling data and/or results from a set of comparable studies of a problem. Pooling in this way provides a larger sample size for evaluation and allows for a stronger conclusion than can be provided by any single study. Meta-analysis yields a quantitative summary of the combined results and current state of the literature.

published over 1994-2013 (Nordhaus and Moffat 2017). Howard and Sterner (2017) provide a more recent published peer-reviewed meta-analysis of existing damage studies (published through 2016) and account for additional features of the underlying studies.<sup>97</sup> They address differences in measurement across studies by adjusting estimates such that the data are relative to the same base period. They also address issues related to double counting by removing duplicative estimates. Dependence across climate-damage estimates can arise over time due to the common practice of calibrating climate-model damage functions based on previous estimates in the climate damage literature. Howard and Sterner’s review identified 35 studies that meet their *a priori* selection criteria, of which 15 were dropped because they duplicated studies already in the sample. Their final sample is drawn from 20 studies that were published through 2015.

Howard and Sterner (2017) present results under several specifications, and their analysis shows that the estimates are somewhat sensitive to defensible alternative modeling choices. Howard and Sterner’s main specifications vary across two dimensions: (1) whether the sample includes estimates from studies that consider large temperature changes (i.e., above 4°C), and (2) whether the econometric specification explicitly accounts for different damage channels underlying the studies, such as studies that attempt to account for the effect of climate impacts on economic productivity, and whether or not the estimates of those damage channels should be additive to the primary damage estimate in the model.

Regarding the first dimension, this report focuses on a specification that includes estimates across the full range of temperature changes considered in the underlying studies. Howard and Sterner’s (2017) reasoning for considering only estimates for temperature changes below 4°C is that, in their modeling, most present value damages occur before 2100 and at or below 4°C.<sup>98</sup> Applying the same logic would lead to the opposite conclusion in the current modeling framework. After incorporating major advancements in the socioeconomics, climate and discounting modules, as discussed in sections 2.1, 2.2, and 2.4, a significant share of the temperature anomaly distribution exceeds 4°C based on RFF-SPs and FAIR1.6.2 over the modeling horizon (2020 to 2300) and a significant amount of estimated discounted damages occur after 2100 (see Section 3). The coefficient estimate on the temperature variable in the specification in Howard and Sterner (2017) used in this report (i.e., the specification that includes estimates of damages at all temperatures, including those above 4°C) is smaller in magnitude than in the specification which limits the analysis to studies that estimate damages at temperatures less than 4°C.<sup>99</sup> Thus, the

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<sup>97</sup> New meta-regressions incorporating more recent global damage estimates are starting to become available. See, for example, working papers by Howard and Sterner (2022), Tol (2022), and Barrage and Nordhaus (2023). Barrage and Nordhaus (2023) explain that the newest version of DICE, DICE 2023, is being developed using a damage function specification based on studies surveyed in Piontek et al. (2021), which overlaps closely with the set of studies reviewed by the IPCC’s AR6 (IPCC 2022).

<sup>98</sup> As noted in the published paper, “...the majority (approximately two-thirds) of the 2015 SCC estimate for DICE 2013R correspond to impacts occurring this century....for which estimates for approximately 4°C or less are more germane” (Howard and Sterner 2017, p. 220).

<sup>99</sup> In a recent follow-up working paper, Howard and Sterner (2022) further explore the uncertainties in the limited number of damage estimates corresponding to temperature increases above 4°C and emphasize that the specification from Howard and Sterner (2017) that includes estimates of damages at all temperatures, which is used in this report, likely produces an underestimate of climate damages.

specification used in this report reflects an estimate of the relationship between temperature and climate damages from Howard and Sterner that leads to a lower estimate of the SC-GHG, all else equal.

Regarding the second dimension, this report focuses on Howard and Sterner’s estimation of combined damage channels—the primary damage coefficient in their model. This choice, to exclude the coefficients on catastrophic and productivity effects, is consistent with the authors’ recommendations in the published paper and follows the method Nordhaus (2019) uses to adjust the default damage function in DICE 2016 to reflect the findings of Howard and Sterner’s meta-analysis. The authors’ rationale for excluding the estimated coefficients on the control variables<sup>100</sup> for catastrophic damages and productivity impacts in the primary specification of the damage function was “because of their mixed [statistical] significance and volatility across the various specifications.” The catastrophic damages coefficient is identified by five older studies which, while illustrative about the potential importance of such effects, are not grounded in empirical evidence or explicit modeling of tipping elements and other effects contemplated by the authors to lead to catastrophes.<sup>101</sup> There is a need for improved methods for quantifying and incorporating these types of important elements of damages in future updates (e.g., through modeling specific tipping points and Earth system feedback effects). See section 3.2 for further discussion of these considerations.

Productivity damages in Howard and Sterner (2017) are identified by four studies (2 statistical and 2 CGE) and the coefficient on the productivity indicator is estimated to be positive but not statistically different from zero in any of the specifications.<sup>102</sup> Given the statistical insignificance of the estimated coefficient on the productivity indicator in the published Howard and Sterner meta-analysis, the SC-GHG estimates presented in this report do not rely on Howard and Sterner’s specifications that include productivity effects. This is consistent with the authors’ recommendations in the published paper, to only consider the inclusion of the productivity impact in sensitivity analysis.<sup>103</sup> However, the question of whether the effects of climate change impacts (e.g., temperature, tropical cyclones, and other extreme weather events) on the economy are only temporary or persistent is an active area of research. Over the past decade, a host of empirical studies have found evidence of temperature changes having persistent effects on the economy (e.g., Dell et al. 2012; Burke et al. 2015; Moore and Diaz 2015; Deryugina and Hsiang 2017; Ricke et al. 2018; Burke and Tanutama 2019; Colacito et al. 2019; Henseler and Schumacher 2019; Kahn et al. 2021; Kumar and Khanna 2019; Bastien-Olvera et al. 2022); this is an important finding because even small changes in economic growth rates accumulate into large economic impacts over time. EPA will continue

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<sup>100</sup> These control variables indicate Howard and Sterner’s categorization of whether the underlying damage estimates account for potential for “catastrophic” impacts or account for the effects of climate change on economic growth.

<sup>101</sup> The 5 studies from which Howard and Sterner (2017) take damage estimates that were considered to include catastrophic damages were: Nordhaus (2014), Nordhaus (2008), Weitzman (2012) via Ackerman et al. (2012), Ackerman et al. (2012) adjusting Hanemann (2008), Meyer and Cooper (1995).

<sup>102</sup> The term “productivity” used in the Howard and Sterner (2017) damage function is distinct from the empirically grounded micro-economic labor productivity described in the DSCIM damages model. Instead, productivity in Howard and Sterner (2017) relates to the ongoing debate about persistence in damages as measured by changes in economic growth over time.

<sup>103</sup> Howard and Sterner (2017) conclude that “...given the debate over the impact of climate change on productivity and economic growth (Dell et al. 2012; Burke et al. 2015; Howard [and Sylvan] 2015), we recommend conducting an analysis of sensitivity to the inclusion of the productivity impact.”

to follow advances in the literature on methodologies for identifying and quantifying productivity effects of climate change. Finally, unlike Howard and Sterner (2017), the model runs performed for this report do not adopt a 25% adder (as used in the DICE model (e.g., Nordhaus 2017)) to account for unknown or missing damages for the meta-analysis-based damage module. Taken together, this report uses the damage function specification (excluding duplicate studies) from Howard and Sterner (2017) that leads to the lowest SC-GHG estimates, all else equal.<sup>104</sup>

### 2.3.4 Comparing the Three Damage Modules

Each of the three damage modules – based on DSCIM, GIVE, and the Howard and Sterner (2017) meta-analysis – is separately estimated in combination with the socioeconomics, climate, and discounting modules described elsewhere in this section. The sectoral damage modules in GIVE and DSCIM are based on different underlying information, data sources, and estimation methods.<sup>105</sup> GIVE and DSCIM are both independent lines of evidence from the meta-analysis-based damage module since the studies underlying each sectoral damage modules in GIVE and DSCIM are not included in Howard and Sterner’s (2017) final sample of studies. Figure 2.3.2 illustrates the shape of the damage function across the three models. Specifically, the figure presents projections of total damages from climate change in 2100 as a function of GMST change. The points represent a random subset of the Monte Carlo simulation (5k of the 10k simulations) where the socioeconomic and climate module parameters are consistent across damage modules (i.e., the first trial of DSCIM takes the same socioeconomic pathways and climate parameters as the first trial of GIVE and the meta-analysis-based damage function). The global damage functions shown here are generated using estimated damages in 2100 (the points) and regressing on temperature and temperature squared in 2100 at the mean (solid line), and quantile regressions at the median (dashed lines), 5<sup>th</sup> to 95<sup>th</sup> (dark shade) and 1<sup>st</sup> to 99<sup>th</sup> (light shade) percentiles. In GIVE and the meta-analysis, the Monte Carlo estimation also samples from the joint distributions of parametric damage function uncertainty. As detailed in Section 2.3.2 and Appendix A.8, the Monte Carlo estimation in GIVE reflects the damage uncertainty in the health and agriculture impact categories, but not energy and coastal.

As seen in Figure 2.3.2, there are notable differences between the damage functions. On average, DSCIM estimates lower damages but predicts a more rapidly increasing damage function beyond 4 degrees Celsius, compared to GIVE that has increasing but consistent damages throughout the temperature range. The meta-analysis-based damage function reflects the explicit quadratic nature of the published Howard and Sterner (2017) damage function. Section 3 presents the resulting SC-GHG estimates based on each

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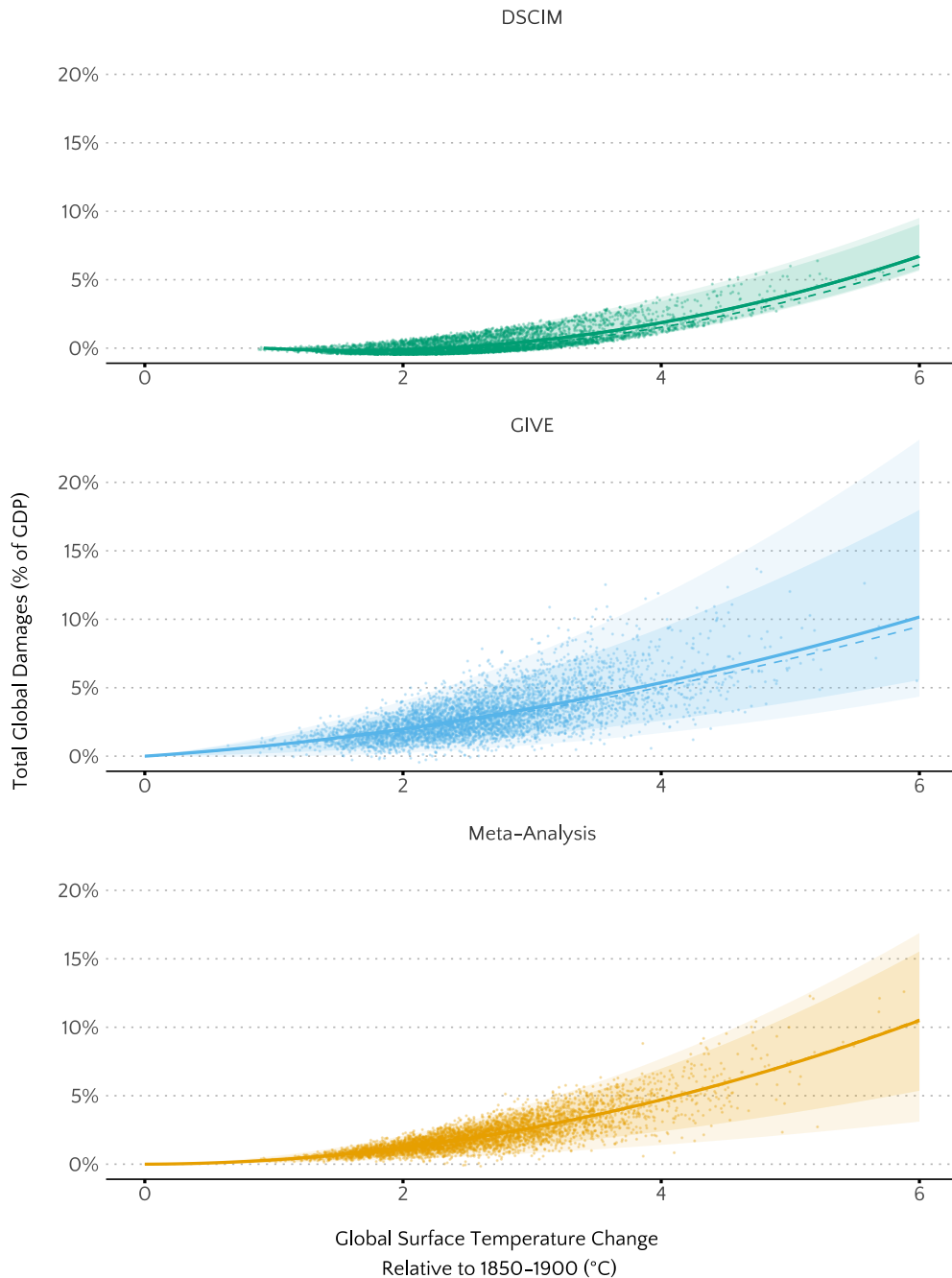
<sup>104</sup> The study author confirmed that EPA selected the paper’s most conservative specification (<https://www.regulations.gov/docket/EPA-HQ-OAR-2021-0317/comments?filter=EPA-HQ-OAR-2021-0317-2398>). This specification of Howard and Sterner’s results (i.e., using the estimated temperature coefficient in specification 7 presented in Table 2 of their paper) is also provided as an alternative damage function option in the GIVE model (Rennert et al. 2022b). When the Howard and Sterner (2017) damage function is used within the GIVE model, the other damage sectors (agriculture, mortality, energy, and coastal) are turned off and the Monte Carlo simulation samples from all relevant model parameter distributions including those underlying the Howard and Sterner (2017) meta-analysis damage parameters.

<sup>105</sup> Only one component of the methodology for calculating coastal damages is common across the two models. Both DSCIM and GIVE rely on the CIAM model developed by Diaz (2016) to estimate the economic damages resulting from projections of SLR.

damage module combined with the socioeconomic and climate modules and discusses the importance of omitted climate impacts and associated damages.



**Figure 2.3.2: Annual Consumption Loss as a Fraction of Global GDP in 2100 due to an Increase in Annual Global Mean Surface Temperature in the three Damage Modules**



GDP loss functions are generated using estimated damages in 2100 (points) and regressing on temperature and temperature squared at the mean (solid line), and quantile regressions at the median (dashed lines), 5<sup>th</sup> to 95<sup>th</sup> (dark shade) and 1<sup>st</sup> to 99<sup>th</sup> (light shade). 5,000 of the 10,000 points for each module are randomly selected to simplify the presentation of damages. DSCIM estimates damages relative to global mean surface temperatures between 2000-2010 and was normalized here to 1850-1900 to be consistent with GIVE and the meta-analysis. GIVE and the meta-analysis presented here include the full uncertainty underlying each module in the Monte Carlo analysis, DSCIM observations present climate and socioeconomic uncertainty (no statistical uncertainty from the underlying damage functions). The IPCC (2021a) notes that present day global mean surface temperatures in the year 2020 are around 1.1 °C above preindustrial (1850-1900) levels.

## 2.4 Discounting Module

GHG emissions are stock pollutants, in which damages result from the accumulation of the pollutants in the atmosphere over time. Because GHGs are long-lived, subsequent damages resulting from emissions today occur over many decades or centuries, depending on the specific GHG under consideration.<sup>106</sup> In calculating the SC-GHG, the stream of future marginal damages, as estimated by the damage modules discussed in Section 2.3, is calculated in terms of reduced consumption (or monetary consumption equivalents). The stream of future damages is then discounted to its present value in the year when the additional unit of emissions was released. Given the long time horizon over which the damages are expected to occur, the approach to discounting greatly influences the present value of future damages.

Arrow et al. (1995) outlined two main approaches to determine the discount rate for climate change analysis, which they labeled “descriptive” and “prescriptive.” The descriptive approach reflects a positive (non-normative) perspective based on observations of people’s actual choices – e.g., savings versus consumption decisions over time, and allocations of savings among more and less risky investments. Advocates of this approach generally call for inferring the discount rate from market rates of return because “no justification exists for choosing [a social welfare function] different from what decisionmakers actually use” (Arrow et al. 1995).

In addition, the Kaldor-Hicks potential compensation test – one theoretical foundation for the benefit-cost analyses in which the SC-GHG will be used – suggests that market rates should be used to discount future benefits and costs. This is because the market interest rate would govern the returns potentially set aside today to compensate future individuals for the climate damages that they bear (e.g., Just et al. 2004). The word “potentially” indicates that there is no assurance that returns will be set aside to provide compensation, and the very idea of compensation is difficult to define in the intergenerational context. On the other hand, societies provide compensation to future generations through investments in human capital and the resulting increase in knowledge, infrastructure and other physical capital, and the maintenance and preservation of natural capital.

In contrast, the prescriptive (normative) approach specifies a social discount rate that formalizes the normative judgments that the decision-maker wants to incorporate into the policy evaluation. That is, it defines from the decision-maker’s perspective how interpersonal comparisons of utility *should* be made and how the welfare of future generations *should* be weighed against that of the present generation. Ramsey (1928), for example, argued that it is “ethically indefensible” to apply a positive pure rate of time preference to discount values across generations.

Additional concerns motivate adjusting descriptive discount rates. Future generations’ preferences regarding consumption versus environmental amenities may not be the same as those today, raising concerns about using the current market rate on consumption to discount future climate-related damages. Furthermore, markets for relatively riskless assets with a maturity similar to an intergenerational horizon, akin to the horizon over which climate change impacts are realized, do not exist (Gollier and Hammit 2014). Others argue that the discount rate should be below market rates to correct

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<sup>106</sup> “GHGs, for example, CO<sub>2</sub>, methane, and nitrous oxide, are chemically stable and persist in the atmosphere over time scales of a decade to centuries or longer, so that their emission has a long-term influence on the climate. Because these gases are long lived, they become well mixed throughout the atmosphere” (IPCC 2007b).

for market distortions and uncertainties or inefficiencies in intergenerational transfers of wealth (Howard and Schwartz 2022).

Further, a concern about discount rates developed using either the descriptive or prescriptive approach is that they tend to obscure important heterogeneity in the population. For instance, many individuals smooth consumption by borrowing with credit cards that have relatively high rates. Some are unable to access traditional credit markets and rely on payday lending operations or other high-cost forms of smoothing consumption. This behavior may reflect rational intertemporal preferences, or it may reflect other factors such as present bias, lack of financial literacy, and other distortionary effects of poverty (Haushofer and Fehr 2014; Lusardi and Mitchell 2014). When evaluating social discount rates, some consideration should be given to the heterogeneity of preferences in the population.

The EPA's analyses rely primarily on the descriptive approach to inform the choice of a discount rate for SC-GHG estimation, consistent with the rationale outlined in IWG TSDs (e.g., IWG 2010, 2021) and EPA's economic analysis guidelines (EPA 2010). With a recognition of its limitations, the IWG found this approach to be the most defensible and transparent given its consistency with both the standard contemporary theoretical foundations of benefit-cost analysis and the approach recommended by OMB's existing guidance.

In 2010, the IWG specifically elected to use three constant discount rates: 2.5%, 3%, and 5% per year. The 3% rate was included as consistent with the default recommendation provided in OMB's Circular A-4 (OMB 2003) guidance for the consumption rate of interest. The IWG found that the consumption rate of interest is the correct discounting concept to use when the future damages from climate change are estimated in consumption-equivalent units, as is done in the IAMs used to estimate the SC-GHG.<sup>107</sup> The 3% rate was roughly consistent with the average rate of return for long-term Treasury notes calculated at the time the OMB guidance was published. The upper rate of 5% was included to represent the possibility that climate-related damages are positively correlated with market returns, which would imply a certainty-equivalent<sup>108</sup> risk-adjusted rate higher than the consumption rate of interest. The low rate, 2.5%, was included to incorporate the concern that interest rates are highly uncertain over time, which would imply a risk-free certainty-equivalent rate lower than the consumption rate of interest. Additionally, a rate below the consumption rate of interest would also be justified if the return to investments in climate mitigation is negatively (or weakly) correlated with the overall market rate of return. The use of this lower rate was also deemed responsive to certain judgments based on the prescriptive or normative approach for selecting a discount rate and related ethical objections about rates of 3% or higher.<sup>109</sup> Further details about selecting these rates are presented in the 2010 TSD (IWG 2010).

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<sup>107</sup> Appendix A.2 provides additional detail on why the consumption discount rate is the appropriate rate to be used in estimating the SC-GHG.

<sup>108</sup> The certainty-equivalent discount rate is the certain discount rate that is equivalent to an uncertain discount rate in terms of the discount factor over a particular horizon (National Academies 2017). See National Academies (2017) for more explanation of this and other discounting terminology.

<sup>109</sup> Circular A-4 (OMB 2003) recognized these concerns when recommending consideration of discount rates below 3% when a rule has important intergenerational benefits or costs. Circular A-4 (2023) likewise recognized these concerns when recommending consideration of discount rates below the near-term social rate of time preference when a rule has important intergenerational benefits or costs (OMB 2023).

Based on a review of the literature and data on consumption discount rates, the public comments received on individual EPA rulemakings, and the February 2021 TSD (IWG 2021), and the National Academies (2017) recommendations for updating the discounting module, this report uses discount rates that reflect more recent data on the consumption interest rate and uncertainty in future rates. The approach presented in this report continues to rely on a descriptive approach to discounting but more fully captures the role of uncertainty in the discount rate in a manner consistent with the other modules. Specifically, rather than using a constant discount rate, the evolution of the discount rate over time is defined following the latest empirical evidence on interest rate uncertainty and using a framework originally developed by Ramsey (1928) that connects economic growth and interest rates. The Ramsey approach explicitly reflects (1) preferences for utility in one period relative to utility in a later period and (2) the value of additional consumption as income changes. The resulting dynamic discount rate provides a notable improvement over the constant discount rate framework for SC-GHG estimation.<sup>110</sup> Specifically, it provides internal consistency within the modeling and a more complete accounting of uncertainty<sup>111</sup> consistent with economic theory (Arrow et al. 2013, Cropper et al. 2014) and the National Academies' (2017) recommendation to employ a more structural, Ramsey-like approach to discounting that explicitly recognizes the relationship between economic growth and discounting uncertainty. The following sections provide an overview of the Ramsey discounting formula and then describe the calibration of the new set of dynamic discount rates.

#### 2.4.1 The Ramsey Formula

The Ramsey formula for discounting is derived from work by Frank Ramsey (1928) and others (Cass 1965, Koopmans 1963) on the optimal level of consumption and saving. The formula describes the optimal consumption discount rate as a function that explicitly reflects: (1) preferences for utility in one period relative to utility in a later period (called the "pure rate of time preference"); and (2) the value of additional consumption as income changes. These factors are combined in the following equation,

$$r_t = \rho + \eta g_t, \quad (2.4.1)$$

where  $r_t$  is the consumption discount rate in year  $t$ ,  $\rho$  is the pure rate of time preference,  $\eta$  is the elasticity of marginal utility with respect to consumption, and  $g_t$  is the representative agent's consumption growth rate in year  $t$ .<sup>112</sup>

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<sup>110</sup> Peer reviewers highlighted this improvement. For example, one reviewer concluded: "The Ramsey formulation adopted in this section is an improvement over past discounting approaches, in my opinion since it allows for dynamic discount rates and long-term intertemporal trade-offs which is key to the climate change issue." As another reviewer put it: "[t]he discounting module applied in the EPA report appropriately represents the biggest advance from the prior SC-CO<sub>2</sub> efforts."

<sup>111</sup> As noted in Circular A-4 (2003), "the longer the horizon for the analysis," the higher the "uncertainty about the appropriate value of the discount rate" (OMB 2003). Or as noted in Circular A-4 (2023), "Because future changes in the social rate of time preference are uncertain but correlated over time, the certainty-equivalent discount rate will have a declining schedule."

<sup>112</sup> The economic framework in this report implicitly assumes an exogenous fixed savings rate. With this assumption, consumption growth and income (GDP) growth are equivalent. A more restrictive assumption that leads to the same result would be to assume that the savings rate is zero and consumption is equivalent to income. Relaxing the fixed savings rate assumption would require adding further complexity to calculate the optimal savings rate in each year.

The pure rate of time preference,  $\rho$ , is the rate at which the representative agent discounts utility in future periods due to a preference for utility sooner rather than later. The elasticity of marginal utility with respect to consumption,  $\eta$ , defines the rate at which the well-being from an additional dollar of consumption declines as the level of consumption increases. In this context, it is common to assume that well-being can be described by an isoelastic utility function, where utility,  $u$ , is a power function with respect to consumption,  $c_t$ , such that

$$u(c_t) = \frac{c_t^{1-\eta}}{1-\eta}. \quad (2.4.2)$$

This function implies that the elasticity of marginal utility with respect to consumption is a constant value,  $-\eta$  (i.e., for a given percent increase in baseline consumption, the benefit of an additional unit of consumption decreases by a proportional percentage). The term,  $g_t$ , defines the projected change in consumption per capita over time. Under the common assumption of a constant savings rate,  $g_t$  would be expected to change with income over time.<sup>113,114</sup> When using the Ramsey formula to estimate the SC-GHG, the per capita consumption growth rate,  $g_t$  is calculated net of baseline climate change damages as estimated by the damage modules described in Section 2.3.

The use of the Ramsey formula provides internal consistency within the modeling between the socio-economic scenarios and the discount rate. With uncertainty in the per capita consumption growth rate, the Ramsey discount rate becomes a dynamic parameter within the modeling framework that reflects how uncertainty about future conditions has implications for how future impacts are valued. Gollier (2014) showed that when there is uncertainty in future consumption growth, the distribution of discount rates defined by the Ramsey formula will have a certainty-equivalent risk-free discount rate path that declines over time, under standard assumptions about individual preferences. This is particularly true when shocks to consumption growth are positively correlated over time, as they are in the probabilistic scenarios described in Section 2.1. The declining certainty-equivalent risk-free discount rate implied by the Ramsey formula reflects that additional climate change damages are a greater burden to society in future states of the world with relatively lower economic growth. Damages in low economic growth states of the world are given greater weight than if those same damages were realized in a future state of the world with relatively higher economic growth, all else equal (Gollier and Weitzman 2010). The declining certainty-equivalent discount rate implied by the Ramsey formula is also consistent with the empirical literature on discount rates under uncertainty (e.g., Newell and Pizer 2003, Bauer and Rudebusch 2023).<sup>115</sup>

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<sup>113</sup> More information on the derivation of the Ramsey formula can be found in Dasgupta (2020) and Gollier (2013).

<sup>114</sup> There is no requirement in the model that the growth in consumption per capita,  $g_t$ , be positive. If  $\rho$  is close to zero, then the discount rate will be negative when  $g_t$  is negative. The SC-GHG estimates in this report include trial years in which the discount rate is negative. Most of these instances are due to negative growth rates in the RFF-SPs, but some trial years have a negative  $g_t$  only after subtracting baseline climate damages as recommended by Kelleher and Wagner (2019). For these trial years, damages grow faster than consumption.

<sup>115</sup> The approach employed in this report should not be confused with applying an exogenously specified declining discount rate. There are similarities, in that incorporating economic uncertainty in the Ramsey equation yields a declining certainty-equivalent discount rate. However, the application of an exogenously specified declining discount rate would fail to capture the way in which the correlation between uncertain climate damages and uncertain economic growth affect estimates of the SC-GHG.

The use of the Ramsey formula also provides internal consistency in that it accounts for correlation between climate change damages and consumption growth when discounting. This correlation is often referred to as the “climate beta,” and is a measure of the covariance of future consumption growth and marginal climate damages (see Appendix A.4 for a detailed discussion). The climate beta can be explicitly represented in the risk-adjusted discount rate (Gollier 2014, Dietz et al. 2018, Howard and Schwartz 2022, Prest 2023). If climate change damages are positively correlated with consumption growth (e.g., if climate damages are higher in wealthier states of the world or if the willingness to pay to avoid climate impacts increases with consumption or emissions), then a higher risk-adjusted discount rate should be used because climate mitigation policies would have a relatively smaller impact on utility in states of the world with a higher consumption levels and a lower marginal utility of consumption. On the other hand, if climate change damages are negatively correlated with consumption growth (e.g., if relatively less adaptation is available at lower consumption levels, or if climate damages slow consumption growth by altering available resources or capital stocks), then a lower risk-adjusted discount rate should be used because climate mitigation policies would have a relatively higher impact on utility in states of the world with lower consumption and a higher marginal utility of consumption. Different types of damages and damages in different regions can correlate differently, or not correlate, with consumption growth, and adaptation and mitigation may affect these relationships.

The approach used for this report is to use the risk-free consumption rate of discount, given by the Ramsey formula, in conjunction with probabilistic growth scenarios and modeling climate change damages under uncertainty. This approach ensures that correlation between climate change damages and economic growth within the model is appropriately captured in the SC-GHG estimates. That is, the SC-GHG is calculated as  $E \left[ \int_{t=0}^T e^{-(\rho+\eta g_t)} md_t \right]$ , where  $e^{-(\rho+\eta g_t)}$  is the Ramsey discount factor at time  $t$  and  $md_t$  is the marginal damages at time  $t$ .<sup>116</sup> The equation inside the expectation operator is calculated for each Monte Carlo trial using the probabilistic scenarios of the RFF-SPs. By using the Ramsey formula, the covariance between economic growth,  $g_t$ , and marginal damages,  $md_t$ , is automatically reflected in the expected value of discounted marginal damages. The SC-GHG is then the value for emissions reductions based on uncertain future returns and is inclusive of the risk premium. Scenarios in which marginal damages are high at the same time consumption growth is high will be discounted at a higher rate when using the Ramsey formula. On the other hand, scenarios in which marginal damages are high when consumption growth is low will be discounted at a lower rate. The Ramsey formula therefore provides an internally consistent approach to capturing these effects, and exogenous adjustments to the discount rate are not required.

Incorporating dynamic discount rates through the application of the Ramsey formula remains widely used in the peer reviewed literature and is consistent with the National Academies’ (2017) recommendations on discounting. It provides important improvements over the use of a static discount rate and incorporates links between the modules used in this report. While offering an important improvement, the Ramsey formula is an approximation of complex economic processes, and future research may provide methodological advancements that further improve the representation of those processes within dynamic discount rates.

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<sup>116</sup> This is the continuous time equation for the SC-GHG. In practice, we estimate the marginal damages on an annual basis. See Appendix A.3 for the discrete time version of this equation.

## 2.4.2 Calibration of Discount Rate Distributions

The National Academies (2017) recommended that the IWG “choose parameters for the Ramsey formula that are consistent with theory and evidence and that produce certainty-equivalent discount rates consistent, over the next several decades, with consumption rates of interest.” The SC-GHG estimates presented in this report adopt a descriptive approach to calibrating the Ramsey parameters, meaning that the parameters are calibrated based on observed interest rate data, consistent with the National Academies’ recommendation. Specifically, the parameters are calibrated following the Newell et al. (2022) calibration approach, as applied in Rennert et al. (2022a, 2022b). Under this approach, the parameters are calibrated such that (1) the decline in the certainty-equivalent discount rate path matches the latest empirical evidence on interest rate uncertainty estimated by Bauer and Rudebusch (2020, 2023) and (2) the average of the certainty-equivalent discount rate over the first decade matches a specified near-term consumption rate of interest. As described below, given the uncertainty about the appropriate starting rate, three near-term target rates (1.5%, 2.0%, and 2.5%) are used based on multiple lines of evidence on observed interest rate data. The calibration of the parameters is carried out using the same probabilistic socioeconomic scenarios presented in Section 2.1 to ensure internal consistency. This approach results in three discount rate paths and is consistent with the National Academies (2017) recommendation to use three sets of Ramsey parameters that reflect a range of near-term certainty-equivalent discount rates consistent with theory and empirical evidence on consumption rate uncertainty and uncertainty surrounding long-run socioeconomic and emissions projections.

***Specifying the near-term target rates.*** The near-term certainty-equivalent discount rate is calibrated based on observed interest rate data. Estimates of the risk-free consumption interest rate – used to represent temporal preferences in benefit-cost analysis – have generally focused on historical returns to long-term Treasury securities backed by the faith and credit of the U.S. Government. In particular, the estimates of the consumption interest rate published in OMB’s Circular A-4 in 2003 are based on the real rate of return on 10-year Treasury Securities (FRED 2023b) from the prior 30 years (1973 through 2002).<sup>117</sup> However, there has been a substantial and persistent decline in real interest rates over the past four decades. Recent research has found that the decline in real interest rates reflects a reduction in the equilibrium real interest rate, suggesting that lower real interest rates are expected to persist (Bauer and Rudebusch 2020, 2023). These changes indicate the need for new estimates of the near-term consumption rate of interest that incorporate recent data.

From 2003 onwards, it is possible to use the 10-Year Treasury Inflation-Protected Securities (TIPS) (FRED 2023c) as a measure of the real rate of return on 10-Year Treasury Securities. Prior to the TIPS introduction, nominal returns on Treasury securities needed to be adjusted for inflation. To use the consumption interest rate as an estimate of social preferences for trading off consumption over time, the inflation adjustment should reflect investor expectations about inflation over the maturity period to produce an estimate of the tradeoff investors believe they are making. There are multiple approaches to adjusting the nominal rate for inflation expectations over the maturity of the security at the time of purchase. Three measures of inflation expectations are considered. The first is a ten-year moving average

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<sup>117</sup> The estimate of the consumption interest rate published in OMB’s Circular A-4 in 2023 is also based on the real rate of return on 10-year Federal Treasury marketable securities from the prior 30 years (1993 to 2022). Using this approach, Circular A-4 (2023) arrives at an estimate of 2.0%.

of the consumer price index (CPI) (FRED 2023a) prior to the year of the security issuance. This measure assumes that recent trends in inflation inform expectations over future inflation. The second is a ten-year moving average of inflation expectations as measured by the Livingston Survey, which is a survey of forecasters about key economic variables.<sup>118</sup> This approach has been used in the economics literature to measure inflation expectations when examining real rates of return (e.g., Newell and Pizer, 2003). The third is the perceived inflation target rate (PTR) from the Federal Reserve's FRB/US model. The PTR is an expectation of long-run inflation estimated from the Survey of Professional Forecasters (SPF). For years before the inception of the SPF, the PTR is estimated econometrically.<sup>119</sup> The PTR has also been used in the economics literature as a measure of inflation expectations when examining real rates of return (e.g., Fuhrer et al. 2012, Bauer and Rudebusch 2017, 2020, 2023).

Table 2.4.1 presents the average real return on 10-Year Treasury securities for each of the three methods used to estimate inflation expectations for two time periods. The first is a 30-year period (1991-2020) following the approach taken by OMB in developing Circular A-4 (2003). The second is a 48-year period (1973-2020), which includes all the years originally used by OMB in developing Circular A-4 (2003) as well as more recent data (2003-2020). The average real returns are lower under the shorter time period, reflecting the decline in real interest rates over recent decades.<sup>120</sup>

*Table 2.4.1: Average Real Return on 10-Year Treasury Securities Based on Inflation Measure*

| Inflation Measure                     | Time Period |           |
|---------------------------------------|-------------|-----------|
|                                       | 1991-2020   | 1973-2020 |
| Consumer Price Index (CPI)            | 1.55%       | 2.12%     |
| Livingston Survey                     | 1.62%       | 2.48%     |
| Perceived Inflation Target Rate (PTR) | 1.98%       | 2.80%     |

<sup>118</sup> Federal Reserve Bank Philadelphia, Consumer Price Index seasonally adjusted, rate of growth over the period from the last monthly or quarterly historical value to the month that is 12 months beyond the survey date or four quarters beyond the survey date, Series name: G\_BP\_To\_12M; <https://www.philadelphiafed.org/-/media/frbp/assets/surveys-and-data/livingston-survey/historical-data/meangrowthrate.xlsx>. Additional information available at <https://www.philadelphiafed.org/surveys-and-data/real-time-data-research/livingston-survey>.

<sup>119</sup> Board of Governors of the Federal Reserve System (US), Trend price inflation measured using survey data on ten-year inflation expectations, Series name: PTR; [https://www.federalreserve.gov/econres/files/data\\_only\\_package.zip](https://www.federalreserve.gov/econres/files/data_only_package.zip). Additional information on the FRB/US model and the PTR are available from the U.S. Federal Reserve at <https://www.federalreserve.gov/econres/us-models-about.htm>.

<sup>120</sup> The average real return on 10-Year Treasury securities has, in general, trended downwards since the 1990s. The average real return on 10-Year Treasury securities in the period 2001-2020 was 1.1% and in the period 2011-2020 it was 0.2%. Based on empirical evidence, Bauer and Rudebusch (2023) utilize the year 1991 as a breakpoint when considering potential shifts in long-run mean of the interest rate process, which coincide with the start of the 30-year period considered in Table 2.4.1. The focus on a 30-year period is also consistent with the approach used by OMB (2003) and OMB (2023) in developing guidance on consumption discount rates in Circular A-4. In addition, under the Ramsey approach used in this report, the certainty-equivalent discount rate for the first 30 years remains close to the near-term target, suggesting shorter time periods may not be adequately capturing the interest rate characteristics over the relevant time period.



The consideration of more recent versus older data depends on whether the downward trend in real interest rates is due to structural changes in the economy that are expected to persist. Bauer and Rudebusch (2023) estimate the current equilibrium real interest using three empirical models for the interest rate process that allows for an evolution in the equilibrium real interest rate over time. Using a time series of 10-Year Treasury securities they estimate current equilibrium real interest rates of 1.3, 1.9, and 2.4%.<sup>121</sup> When using a longer time series of long-term government securities, Bauer and Rudebusch (2023) estimate current equilibrium real interest rates of 1.5%, 2.3%, and 3.0%.<sup>122</sup>

Other government assessments of consumption interest rates suggest a focus on a similar range. The U.S. Congressional Budget Office's Long-Term Economic Projections forecast real rates on 10-Year Treasury securities that average 1.5% over the next decade and exceed 2% by 2050 (CBO 2022, 2023). The most recent Social Security Administration Trustees report (SSA 2023) uses three projections of the long-run real interest rate from 2035 to 2100 of 1.8%, 2.3%, and 2.8% based on their assessment of historical trends in the real interest rate.

The range of consumption interest rates informed by the analysis of Treasury Securities is also consistent with recent empirical evidence of long-run discount rates implied by real estate markets. In an analysis of long-run and perpetual housing ownership contracts in the United Kingdom and Singapore, Giglio et al. (2015) find that the discount rate for 100-year claims is 2.6%. The authors argue that since real estate is a risky asset, this value provides an upper bound for the long-run risk-free rate of interest (Giglio et al. 2015, Giglio et al. 2021).

The empirical evidence on central tendencies for the consumption interest rate is also consistent with recent surveys of economists and technical experts on the appropriate discount rate. Drupp et al. (2018) surveyed economists who have published at least one paper on discounting in a leading economics journal about the appropriate social discount rate, finding a mean of 2.3% and a median of 2%. Howard and Sylvan (2020) surveyed experts who have published at least one article related to climate change in a leading economics or environmental economics journal about the appropriate discount rate for calculating the SC-GHG, also finding a mean of 2.3% and a median of 2%. Pindyck (2019) also surveyed economists on discounting and other topics related to the SC-GHG and found a mean discount rate of 2.7% and a median of 2.0%. The 2% median value of the social discount rate from these surveys is often used in the academic literature (Hänsel et al. 2020, Howard and Sylvan 2020).

The National Academies (2017) recommended the use of “three sets of Ramsey parameters, generating a low, central, and high certainty-equivalent near-term discount rate, and three means and ranges of SC-CO<sub>2</sub> estimates.” Recent studies have found empirical evidence suggestive of a structural break in the

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<sup>121</sup> Time series of 10-Year Treasury securities from 1968-2019 with a PTR based inflation adjustment. The lower estimates in these two ranges are from Bauer and Rudebusch's (2020) univariate unobserved-components (UC) model and the higher estimate is from two autoregressive (AR) model based on Newell and Pizer (2003). When using 1-Year Treasury securities Bauer and Rudebusch (2023) find lower estimates of the equilibrium real interest rate ranging from 0.5% to 1.3%.

<sup>122</sup> The lower estimates in these two ranges are from Bauer and Rudebusch's (2020) univariate unobserved-components (UC) model and the higher estimate is from two autoregressive (AR) model based on Newell and Pizer (2003). In their online appendix, Bauer and Rudebusch (2023) use a time series of long-term government securities from Newell and Pizer (2003), updated to include more recent data, that spans 1798-2019 and uses a ten-year moving average of the Livingston Survey CPI expectation as inflation adjustment after 1954.

interest rate process sometime during the 1990s that has been associated with declining equilibrium interest rates in recent decades (e.g., Del Negro et al. 2017, Christensen and Rudebusch 2019, and Bauer and Rudebusch 2020). Based on empirical evidence, Bauer and Rudebusch (2023) utilize the year 1991 as a breakpoint when considering potential shifts in long-run mean of the interest rate process. Given the evidence of structural shifts in the interest process beginning in the 1990s, and the precedent for using 1991 as a reasonable and empirically formed breakpoint, this report places greater focus on the range of mean interest rate estimates from 1991-2020 presented in Table 2.4.1. To cover that range, this report includes a half a point spread in certainty-equivalent near-term target rates of 1.5% to 2.0%. Given the potential value in considering a longer time series, this report also considers a third near-term target rate of 2.5% reflective of the average of the Table 2.4.1 estimates using the longer time series<sup>123</sup>, which is also consistent with the lines of evidence above suggesting a consumption interest rate of slightly above 2%. Therefore, considering the multiple lines of evidence on the appropriate certainty-equivalent near-term rate, the modeling results presented in this report consider a range of near-term target rates of 1.5%, 2.0%, and 2.5%. This range of rates allows for a symmetric one point spread around 2.0%.

**Calibration of Ramsey parameters.** Calibration of the Ramsey parameters follows Rennert et al. (2022a, 2022b) using the specified set of near-term discount rates to generate a certainty-equivalent discount rate path. Rennert et al. (2022a, 2022b) apply the Newell et al. (2022) calibration approach to the same set of probabilistic socioeconomic scenarios presented in Section 2.1 and adopted in this report. The Ramsey parameters,  $\rho$  and  $\eta$ , were calibrated to meet two conditions. First, the average certainty-equivalent rate over the first 10 years is equal to the near-term target rate. Second, the shape of the certainty-equivalent discount rate path over the time horizon fits the empirical estimates of Bauer and Rudebusch (2023).<sup>124</sup> The resulting calibrated values of the Ramsey formula parameters are presented in Table 2.4.2.

*Table 2.4.2: Calibrated Ramsey Formula Parameters*

| Near-Term Target<br>Certainty-Equivalent Rate | $\rho$ | $\eta$ |
|-----------------------------------------------|--------|--------|
| 1.5%                                          | 0.01%  | 1.02   |
| 2.0%                                          | 0.20%  | 1.24   |
| 2.5%                                          | 0.46%  | 1.42   |

Source: Rennert et al. (2022b)

Figure 2.4.1 presents the resulting distribution of time-averaged discount rates using the calibrated  $\rho$  and  $\eta$  associated with each of the three near-term target rates. The near-term certainty equivalent rate should not be confused with the constant discount rate used by the IWG in earlier estimates. Because of uncertainty in future consumption growth, the certainty-equivalent risk-free discount rate declines over

<sup>123</sup> The average across the estimate in Table 2.4.1 from the window 1973-2020 using different approaches to adjust for inflation is 2.47%, which rounded to one significant digit is 2.5%.

<sup>124</sup> Additional details of the calibration methodology are available in Newell et al. (2022).

time.  $\rho$  and  $\eta$  are calibrated so that the average certainty-equivalent rate over the first 10 years is equal to the near-term target rate conditional on the RFF-SPs.<sup>125</sup>

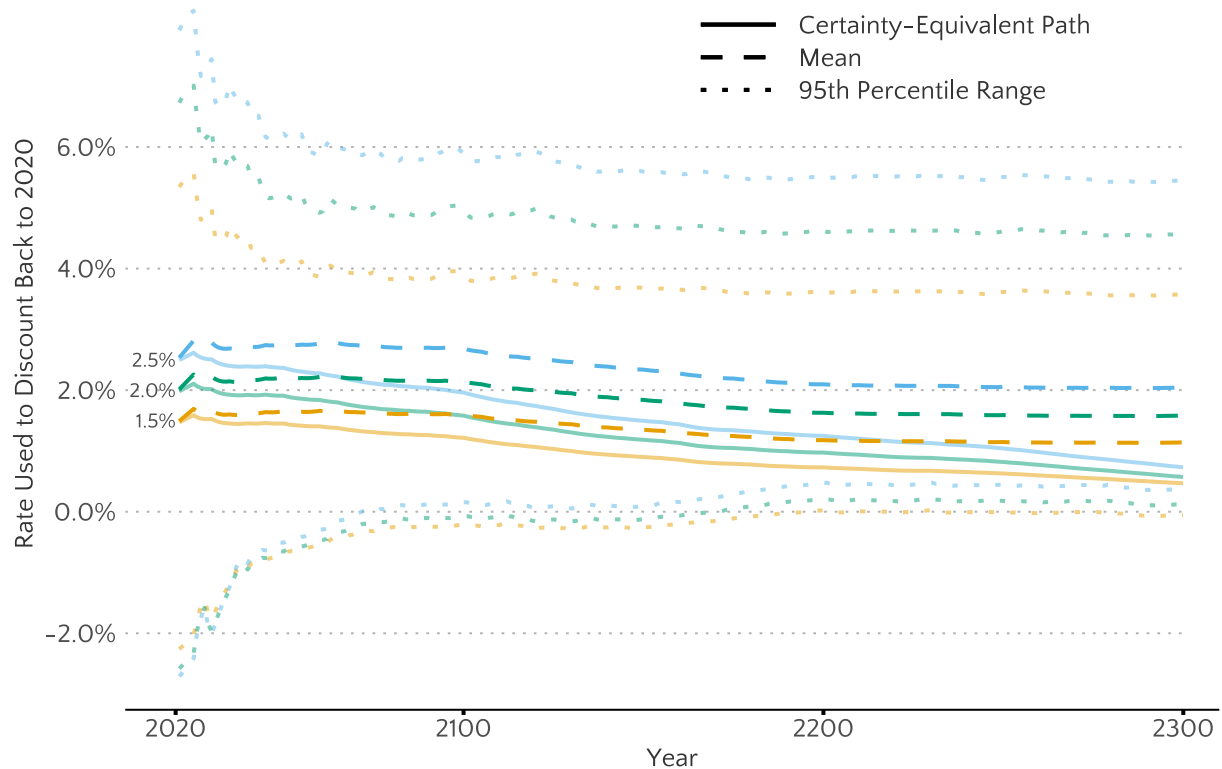
The mean and 95<sup>th</sup> percentile range of the discount rate used to discount climate damages back to 2020 for the RFF-SPs probabilistic growth scenarios are presented using dashed and dotted lines. The solid lines illustrate the certainty-equivalent risk-free discount rate that would lead to the same average discount factor over a specific time horizon as using the full distribution of dynamic discount rates to calculate a distribution of discount factors.<sup>126</sup> This path is the same as the calibrated certainty-equivalent risk-free term structures presented in Rennert et al. (2022a).

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<sup>125</sup> As mentioned previously, the Ramsey approach used for this estimate also accounts for the correlation between climate change damages and economic growth. This is not accounted for by a constant discount rate. Ignoring this correlation – as is the case with a constant discount rate approach – can lead to overestimating the SC-GHG if there is a positive correlation between growth and marginal damages. See, for example Figure 5 in Newell et al. (2022) for an illustration of this potential.

<sup>126</sup> For each trial in the RFF-SPs, a single discount rate is used to discount climate damages. For each year, regional damages are aggregated to global damages and discounted using the global growth rate and the calibrated Ramsey parameters in Table 2.4.2. Theoretically, it is possible to discount regional damages using region-specific growth rates and then aggregate them to global damages. However, as noted by the National Academies (2017), using region-specific discount rates would require Ramsey parameters calibrated for each region. EPA is not aware of peer-reviewed economic studies that have developed an approach to calibrating the Ramsey parameters at a country or region level using empirical evidence consistent with the National Academies' (2017) recommendations. The EPA will continue to follow the scientific literature on probabilistic socioeconomic scenarios and potential regional calibration of Ramsey parameters.

Figure 2.4.1: Distribution of the Dynamic Discount Rates



The range of the dynamic discount rates used to discount climate damages back to 2020 in any one year for the three near-term target rates is summarized by the mean (dashed lines) and 5<sup>th</sup> to 95<sup>th</sup> percentiles (dotted lines). Also shown here is an illustration of the corresponding certainty-equivalent risk-free path (solid lines) implied by the calibration procedure described in Section 2.4.2. During the calibration, Newell et al.(2022) place additional constraints on the rates in each trial such that rates are allowed to go negative but cannot remain negative for the duration of the time period (2020-2300).

While the certainty-equivalent path illustrates the declining certainty-equivalent risk-free discount rate implied by the Ramsey formula, it is important to emphasize that this does not illustrate the discount rate used to estimate the SC-GHG values. First, an exogenous, certainty-equivalent declining discount rate is not used to discount climate damages; each scenario is discounted using the calibrated  $\rho$  and  $\eta$  values presented here and the specific consumption growth rate for that scenario. Second, the consumption growth rate used for discounting is net of baseline climate damages for each model (Kelleher and Wagner 2019).

The calibration approach and resulting Ramsey parameters presented above are consistent with the National Academies' (2017) recommendation to use a descriptive calibration based on empirical interest rate data. The resulting parameters presented in Table 2.4.2 are also within the ranges of values of  $\rho$  and  $\eta$  used in the peer-reviewed literature, including many studies that state their parameter choices are based on prescriptive reasoning (see, e.g., Nesje et al. 2023). For example, the IWG (2010) noted that most papers in the climate change literature adopt values for  $\eta$  in the range of 0.5 to 3, although not all authors articulate whether their choice is based on prescriptive or descriptive reasoning (IWG 2010). The IPCC AR5 report found values of  $\eta$  in the literature in the range of 1 to 4 (IPCC 2014b). Values between 1

and 1.45, consistent with the calibrated range in Table 2.4.2, have been commonly used in recent peer-reviewed studies (Lemoine 2021, Hänsel et al. 2020, Glanemann et al. 2020, Tol 2019, Dietz and Venmans 2019, Nordhaus 2018b, Burke et al. 2018, Adler et al. 2017). The Drupp et al. (2018) survey asked economists about the most appropriate values for  $\eta$ , and found a median (mean) value of 1 (1.35), and a mode value (i.e., the most frequently provided response) of 1.

With respect to the pure rate of time preference, the calibrated values presented in Table 2.4.2 are also within the ranges of  $\rho$  used in peer-reviewed literature. The vast majority of papers in the climate change literature adopt values for  $\rho$  in the range of 0% to 2% per year, with most studies in the lower end of the range (IPCC 2014a). The selection of rates on the lower end of that range tend to emerge from ethical concerns. Some have argued that to use any value other than  $\rho = 0$  would unjustly discriminate against future generations (e.g., Arrow et al. 1995, Stern 2006). When Drupp et al. (2018) surveyed economists about the most appropriate values for  $\rho$ , the experts' responses had a median (mean) value of 0.5% (1.1%), and a mode value of 0. However, even under the case of intergenerational neutrality, a small positive pure rate of time preference may be appropriate to account for the probability of unforeseen cataclysmic events (Stern 2006).<sup>127</sup> Furthermore, it has been argued that very small values of  $\rho$  can lead to an unreasonable rate of optimal savings (Arrow et al. 1995), particularly with  $\eta$  around 1 (Dasgupta 2008, Weitzman 2007).

Regardless of the theoretical approach used to derive the discount rate(s), there remain inherent conceptual and practical difficulties of adequately capturing consumption trade-offs over many decades or even centuries. While this report relies on the descriptive approach for selecting specific discount rates based on observed preferences for temporal tradeoffs of consumption, the EPA is aware of the normative dimensions of both the debate over discounting in the intergenerational context and the consequences of selecting one discount rate over another.

## 2.5 Risk Aversion

The impacts associated with GHG emissions present substantial new risks and exacerbate existing risks to human health and welfare (USGCRP 2018b, NIC 2021). This raises the question of how to account for individuals' preferences over these risks in the valuation of climate damages. Individuals are typically not indifferent between a situation with a certain outcome and a situation with a risky outcome whose expected value is the same as the certain outcome. That is, in most decision-making processes individuals tend to be risk averse. This is evident by the existence of voluntary insurance markets where individuals demonstrate a positive willingness to pay to reduce risk exposure.

U.S. regulatory benefit-cost analyses to date commonly assume risk neutrality (i.e., zero risk aversion). This assumption is justified in cases where idiosyncratic risks can be pooled across regulations, are uncorrelated with baseline economic uncertainty, or are shared across large populations (OECD 2018). However, the largest climate change risks are collective in nature, affecting large shares of the population, and, therefore, may not be diversifiable (Heal and Kriström 2002). The marginal damages are also expected to be correlated with baseline consumption (inclusive of baseline climate change damages) and

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<sup>127</sup> Stern (2006) assumes a pure rate of time preference of 0.1%. This reflects a 91% probability of the human race surviving 100 years.

may add to society's overall risk (National Academies 2017, Dietz et al. 2018). Therefore, in the case of climate change risk reductions, individuals are expected to have a positive willingness to pay for that reduced risk exposure beyond the value of the mean damages. The peer reviewed climate economics literature has demonstrated the importance of accounting for risk aversion in estimates of the SC-GHG (e.g., Anthoff et al. 2009, Cai et al. 2016, Lemoine 2021, van den Bremer and van der Ploeg 2021).

In the EPA's analyses relying on the IWG SC-GHG estimates to date risk aversion was incorporated through adjustments to the discount rate and through consideration of the fourth estimate reflecting the 95<sup>th</sup> percentile for a 3% discount rate. However, in the IWG's 2010 TSD, the IWG acknowledged the limitations of these approaches to provide a unified framework for valuing risk changes. For the SC-GHG estimates presented in this report, the value of risk associated with marginal GHG emissions is explicitly incorporated into the modeling following the economic literature and consistent with the National Academies' (2017) recommendations.

Assuming a time separable welfare function with representative agent utility  $u(\cdot)$  and per capita consumption  $c_t$ , the SC-GHG is defined as

$$SC-GHG = \frac{E \left[ \int_0^T e^{-\rho t} u'(c_t) m d_t dt \right]}{u'(c_0)}, \quad (2.5.1)$$

where  $m d_t$  are the marginal damages associated with emissions in a given year, and  $c_0$  is per capita consumption in the initial period. That is, the SC-GHG is the expected marginal changes in utility normalized by the marginal utility of consumption to convert to a willingness to pay in monetary units. Setting aside uncertainty in future populations for ease of exposition, a second order Taylor expansion of  $u'$  around  $E[c_t]$  allows the SC-GHG to be decomposed as

$$SC-GHG \approx \int_0^T \frac{e^{-\rho t}}{u'(c_0)} \left\{ \underbrace{u'(E[c_t])E[m d_t]}_{\text{Expected Damages}} + \underbrace{\frac{1}{2}u'''(E[c_t])E[m d_t]Var(c_t)}_{\text{Precautionary}} + \underbrace{Cov(u'(c_t), m d_t)}_{\text{Insurance}} \right\} dt. \quad (2.5.2)$$

This approximation is purely for ease of decomposing the SC-GHG to understand the role of uncertainty and is not used in estimating the SC-GHG in this report. The first term in the braces on the right-hand side of equation (2.5.2) is the change in utility from the expected marginal damages, which drives the willingness to pay for the expected marginal damages. The second two terms incorporate the way in which risk impacts the SC-GHG estimates and have been referred to as the precautionary and insurance channels, respectively (Kimball 1990).<sup>128</sup> The precautionary term captures the result that climate damages are more impactful when consumption is lower, all else equal, leading the returns to mitigation to increase with uncertainty in future consumption. The insurance term, also referred to as the risk premium, captures the covariance between marginal utility along the baseline and marginal damages. This term incorporates the climate beta, which is a measure of the degree to which climate damages covary with

<sup>128</sup> The second and third components on the right-hand side of equation (2.5.2) are sometimes also referred to as the diversifiable and non-diversifiable components of risk valuation (OECD 2018).

economic growth (see, for example, Dietz et al. 2018 and Appendix A.4 for a discussion). In other words, the precautionary channel represents the willingness to pay to avoid the additional climate change risk itself and the insurance channel represents the willingness to pay to avoid the broader change in society's risk based on how climate change damages intersect with economic growth. Lemoine (2021) shows that the insurance term can be further broken down into a term that expresses how climate damages scale with the broader economy and an explicit growth insurance term that accounts for uncertainty about the impact of marginal emissions on the growth rate of consumption.

The IWG SC-GHG estimates used by EPA to date have focused on explicitly quantifying the first component in equation (2.5.2). Incorporating the precautionary and insurance channels into the estimation requires probabilistic socioeconomic scenarios, which were not available at the time those estimates were developed. Instead, the IWG partially incorporated the impact of risk into the estimates through adjustments to the discount rates. The motivation for using a lower 2.5% discount rate to capture risk in future economic conditions was premised on the precautionary channel. The motivation for using a higher 5% discount rate was premised on the insurance channel if there is a positive covariance between economic conditions and climate change damages.<sup>129</sup> The fourth value (the 95<sup>th</sup> percentile at a 3% discount rate) was included to represent the extensive evidence in the scientific and economic literature of the potential for lower-probability, higher-impact outcomes from climate change, which would be particularly harmful to society. Absent formal inclusion of risk aversion in the modeling, considering values above the mean in a right skewed distribution with long tails acknowledges society's preference for avoiding risk.

Accounting for risk aversion more explicitly in the analysis allows valuation of the precautionary, insurance, and other channels based on the specific evidence of future economic uncertainty and the correlation with marginal climate change damages presented in Sections 2.1 and 2.3. That is, the value of risk aversion is incorporated into the SC-GHG estimates based on the marginal climate change risk reductions identified by the modeling as opposed to through exogenous adjustments. Explicitly incorporating risk aversion into the analysis requires a functional form for the representative agent's utility function. The most commonly used utility function in the climate economics literature and one consistent with the approach to discounting identified in Section 2.4, is the isoelastic utility function,  $u(c_t) = c_t^{1-\eta}/(1-\eta)$ , where utility is a power function with respect to consumption. If the utility function is assumed to follow an isoelastic function, the definition of the SC-GHG in equation (2.5.1) reduces to the expected value of the marginal damages discounted using the Ramsey formula,

$$SC - GHG = E \left[ \int_0^T e^{-(\rho+\eta g_t)t} m d_t dt \right] \quad (2.5.3)$$

where  $g_t$  is the time averaged per capita consumption continuous growth rate through time  $t$ . Therefore, by discounting via the Ramsey formula as detailed in Section 2.4 and incorporating uncertainty throughout the modeling process as detailed in Sections 2.1-2.3, the SC-GHG estimates incorporate the climate risk through the precautionary and insurance channels.

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<sup>129</sup> If there is a negative covariance between economic growth and climate change damages a downward adjustment in the discount rate would be warranted (Dietz et al. 2018).

Within the isoelastic utility function, the single parameter,  $\eta$ , has a role in reflecting both intertemporal and risk preferences which can present challenges in calibrating the utility function. As noted in Section 2.4, the calibrated values for  $\eta$  presented in Table 2.4.2 are consistent with the calibrated range (1 to 1.45) that has been commonly used in recent peer reviewed studies employing an isoelastic utility function (Lemoine 2021, Hänsel et al. 2020, Glanemann et al. 2020, Tol 2019, Dietz and Venmans 2019, Nordhaus 2018b, Burke et al. 2018, Adler et al. 2017). However, while that range of values may be appropriate for  $\eta$  in its role representing intertemporal preferences, they may be too conservative for  $\eta$  in its role representing risk preferences. Some have suggested that values of  $\eta$  between 2 and 10 would be required to match empirical and experimental evidence on rates of risk aversion (Croston and Traeger 2014, Jensen and Traeger 2014, Cai et al. 2016, Cai and Lontzek 2019, Daniel et al. 2019, Okullo 2020, Lemoine 2021, Jensen and Traeger 2021, Van den Bremer and Van der Ploeg 2021). To address this calibration challenge, some recent SC-GHG studies have used alternative utility function specifications (e.g., Epstein-Zin specifications) that allow for the separation of intertemporal and risk preferences (Cai et al. 2016, Daniel et al. 2019, Cai and Lontzek 2019, Okullo 2020, Lemoine 2021, Van den Bremer and Van der Ploeg 2021). These studies can incorporate a higher rate of relative risk aversion without affecting the calibration of the intertemporal preferences. While these approaches have promise for improving the calibration of risk preferences, they are relatively new in the climate economics literature, computationally complex, and require additional assumptions (e.g., timing of uncertainty resolution) for which there is no consensus in the literature. For these reasons, these alternative utility functions are not used in this report, but they are worthy of additional investigation, consistent with recommendations of the National Academies (2017). Furthermore, the use of an isoelastic utility function via equation (2.5.3) remains widely used in the peer reviewed literature and is consistent with the National Academies' (2017) recommendations on robustly capturing the value uncertainty through probabilistic scenario, climate, and damage function models in conjunction with a Ramsey-like approach to discounting. However, because the calibrated values of  $\eta$  using the isoelastic utility function may be low from a risk aversion perspective, the value of reducing climate change risk included in the SC-GHG estimates will likely be an underestimate, holding all else equal.

When using the damage module based on GIVE and Howard and Sterner (2017), the SC-GHG is calculated using equation (2.5.3) for a global representative agent. Implicit in the use of a global representative agent is that all risks can be pooled at the global level. This is the model developers' default approach in GIVE, and the global nature of the Howard and Sterner (2017) damage module precludes other assumptions. However, when using the DSCIM damage module, a conceptually similar approach is applied but, following the model developers' default approach, a different assumption on risk pooling is applied. Specifically, when the DSCIM damage module is used, it is assumed that risks associated with uncertainty in the climate response and future socioeconomic conditions can be pooled globally, but damage function risks (conditional on a given level of climate change and RFF-SP socioeconomic realization) are pooled at the damage function's impact region level. All else equal, assuming that risk can be pooled across broader geographic areas reduces the value of risk reductions within the SC-GHG estimates.



## 3 Modeling Results

### 3.1 Social Cost of Carbon (SC-CO<sub>2</sub>), Methane (SC-CH<sub>4</sub>), and Nitrous Oxide (SC-N<sub>2</sub>O) Estimates by Damage Module

This section presents the SC-GHG values estimated using the methodological updates described in Section 2. The combination of using three specifications of the damage module over the modeling time horizon<sup>130</sup> and three near-term target discount rates produces nine separate distributions of discounted marginal damages for each emissions year and GHG. Each distribution consists of 10,000 estimates based on draws from the distributions of uncertain parameters in each module.<sup>131</sup> Given the consideration of multiple lines of evidence in the damage module and multiple near-term discount rates, the results are first presented separately for each of the three damage modules by discount rate.<sup>132</sup> The means of the distributions of discounted marginal damages are the certainty-equivalent SC-GHGs. Table 3.1.1, Table 3.1.2, and Table 3.1.3 show the certainty-equivalent SC-CO<sub>2</sub>, SC-CH<sub>4</sub>, and SC-N<sub>2</sub>O estimates, respectively, in ten-year increments for emissions years 2020-2080 by damage module and near-term discount rate.<sup>133</sup> As expected, estimates based on a higher near-term discount rate are consistently lower, while lower near-term discount rates result in higher SC-GHG estimates independent of the damage module. There is some variation in the SC-GHG estimates across the three damage modules. This is expected given that the damage modules are, at least to some extent, measuring different categories of damages and with different approaches. The SC-GHG estimates based on the meta-analysis damage module tend to be higher than those based on the GIVE damage module for CO<sub>2</sub> and N<sub>2</sub>O, with the difference increasing for higher near-term target discount rates. This suggests differences across these two models as to the potential damages from climate change in the near-term. The DSCIM-based estimates tend to be lower than the GIVE and meta-analysis estimates initially, but increase at a faster rate over time, generally exceeding the SC-CO<sub>2</sub> and SC-N<sub>2</sub>O from the other specifications for emissions after 2050. These trends reflect differences in the relative slopes of the damage functions across the three models. This relationship changes over time due to the time-dependent nature of GHG emissions, the resulting paths of temperature anomalies, the shape of the damage functions, and the relationship of these interactions with discounting. For CH<sub>4</sub>, which has a notably shorter atmospheric lifetime than the other two gases, the SC-CH<sub>4</sub> estimates based on the DSCIM damage module remain lower than the estimates from the other two models through 2080.

<sup>130</sup> As mentioned in Section 1.2, the National Academies recommended that the modeling time horizon “extend far enough in the future to provide inputs for estimation of the vast majority of discounted climate damages.” In the case of models presented here, the discounted streams of marginal damages in all models and discount rates peak by the end of the century (2100) and begin to steadily decline through the end of the modeling time horizon (2300)—capturing the majority of the quantified discounted damages associated with the emissions of a metric ton of CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O.

<sup>131</sup> Monte Carlo methods are used to run the combined suite of modules 10,000 times. In each simulation the uncertain parameters are represented by random draws from their defined probability distributions.

<sup>132</sup> Estimates in this report are discounted back to the year of emissions and presented as certainty-equivalent values that account for uncertainty in the socioeconomic scenarios. See Appendix A.3 for more information on how those transformations were made and Section 4 for how they can be used in analyses.

<sup>133</sup> Values in Table 3.1.1, Table 3.1.2, and Table 3.1.3 are rounded to two significant figures.

For all three damage modules, the SC-GHG estimates increase over time – i.e., the societal harm in 2030 from one metric ton emitted in 2030 is greater than the harm in 2020 caused by one metric ton emitted in 2020. Emissions further in the future produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change and because income is growing over time. As income grows so does the willingness to pay to avoid economic damages.

*Table 3.1.1: Social Cost of Carbon (SC-CO<sub>2</sub>) by Damage Module, 2020-2080 (in 2020 dollars per metric ton of CO<sub>2</sub>)*

| Emission Year | Near-Term Ramsey Discount Rate and Damage Module |      |               |                     |      |               |                     |      |               |
|---------------|--------------------------------------------------|------|---------------|---------------------|------|---------------|---------------------|------|---------------|
|               | 2.5% Near-Term Rate                              |      |               | 2.0% Near-Term Rate |      |               | 1.5% Near-Term Rate |      |               |
|               | DSCIM                                            | GIVE | Meta-Analysis | DSCIM               | GIVE | Meta-Analysis | DSCIM               | GIVE | Meta-Analysis |
| 2020          | 110                                              | 120  | 120           | 190                 | 190  | 200           | 330                 | 310  | 370           |
| 2030          | 140                                              | 150  | 150           | 230                 | 220  | 240           | 390                 | 350  | 420           |
| 2040          | 170                                              | 170  | 170           | 280                 | 250  | 270           | 440                 | 390  | 460           |
| 2050          | 210                                              | 200  | 200           | 330                 | 290  | 310           | 500                 | 430  | 520           |
| 2060          | 250                                              | 220  | 230           | 370                 | 310  | 350           | 550                 | 470  | 570           |
| 2070          | 280                                              | 240  | 250           | 410                 | 340  | 380           | 600                 | 490  | 610           |
| 2080          | 320                                              | 260  | 280           | 450                 | 360  | 410           | 640                 | 510  | 650           |

*Table 3.1.2: Social Cost of Methane (SC-CH<sub>4</sub>) by Damage Module, 2020-2080 (in 2020 dollars per metric ton of CH<sub>4</sub>)*

| Emission Year | Near-Term Ramsey Discount Rate and Damage Module |       |               |                     |       |               |                     |       |               |
|---------------|--------------------------------------------------|-------|---------------|---------------------|-------|---------------|---------------------|-------|---------------|
|               | 2.5% Near-Term Rate                              |       |               | 2.0% Near-Term Rate |       |               | 1.5% Near-Term Rate |       |               |
|               | DSCIM                                            | GIVE  | Meta-Analysis | DSCIM               | GIVE  | Meta-Analysis | DSCIM               | GIVE  | Meta-Analysis |
| 2020          | 470                                              | 1,600 | 1,700         | 850                 | 1,900 | 2,200         | 1,500               | 2,500 | 2,900         |
| 2030          | 1,100                                            | 2,300 | 2,300         | 1,600               | 2,800 | 2,800         | 2,400               | 3,500 | 3,700         |
| 2040          | 1,900                                            | 3,300 | 2,900         | 2,500               | 3,800 | 3,500         | 3,300               | 4,700 | 4,500         |
| 2050          | 2,700                                            | 4,200 | 3,700         | 3,400               | 4,900 | 4,400         | 4,300               | 5,900 | 5,600         |
| 2060          | 3,500                                            | 5,000 | 4,400         | 4,200               | 5,800 | 5,300         | 5,200               | 7,000 | 6,700         |
| 2070          | 4,200                                            | 5,700 | 5,100         | 5,100               | 6,600 | 6,200         | 6,100               | 7,900 | 7,800         |
| 2080          | 5,100                                            | 6,300 | 5,900         | 6,000               | 7,300 | 7,100         | 7,100               | 8,800 | 8,900         |

*Table 3.1.3: Social Cost of Nitrous Oxide (SC-N<sub>2</sub>O) by Damage Module, 2020-2080 (in 2020 dollars per metric ton of N<sub>2</sub>O)*

| Emission Year | Near-Term Ramsey Discount Rate and Damage Module |        |               |                     |         |               |                     |         |               |
|---------------|--------------------------------------------------|--------|---------------|---------------------|---------|---------------|---------------------|---------|---------------|
|               | 2.5% Near-Term Rate                              |        |               | 2.0% Near-Term Rate |         |               | 1.5% Near-Term Rate |         |               |
|               | DSCIM                                            | GIVE   | Meta-Analysis | DSCIM               | GIVE    | Meta-Analysis | DSCIM               | GIVE    | Meta-Analysis |
| 2020          | 30,000                                           | 38,000 | 38,000        | 49,000              | 55,000  | 58,000        | 81,000              | 85,000  | 96,000        |
| 2030          | 40,000                                           | 47,000 | 46,000        | 63,000              | 67,000  | 69,000        | 98,000              | 100,000 | 110,000       |
| 2040          | 52,000                                           | 57,000 | 55,000        | 77,000              | 78,000  | 81,000        | 120,000             | 110,000 | 130,000       |
| 2050          | 64,000                                           | 67,000 | 66,000        | 93,000              | 91,000  | 95,000        | 140,000             | 130,000 | 150,000       |
| 2060          | 77,000                                           | 75,000 | 76,000        | 110,000             | 100,000 | 110,000       | 150,000             | 140,000 | 160,000       |
| 2070          | 89,000                                           | 82,000 | 84,000        | 120,000             | 110,000 | 120,000       | 170,000             | 150,000 | 180,000       |
| 2080          | 100,000                                          | 89,000 | 94,000        | 140,000             | 120,000 | 130,000       | 190,000             | 160,000 | 200,000       |

For a given near-term target discount rate, the certainty-equivalent SC-GHG estimate is the value applied to GHG emission changes in benefit-cost analysis (see Section 2.5 for a definition of the SC-GHG). These certainty-equivalents are calculated over a distribution of the discounted marginal damages reflecting the full range of quantified uncertainties incorporated into the modeling (see discussion throughout Section 2, and the summary in Appendix A.8, for a description of the quantified uncertainty in each module). Figure 3.1.1 shows the full distribution of discounted marginal damages per metric ton of CO<sub>2</sub> for emissions in 2030, where the boxes span the inner quartile range (25<sup>th</sup> to 75<sup>th</sup> quantile), whiskers extend to the 5<sup>th</sup> (left) and the 95<sup>th</sup> (right) quantiles.<sup>134</sup> The vertical lines inside of the boxes mark the median of each distribution, and the points inside of the boxes and dollar estimates on top of the boxes mark the certainty-equivalent SC-CO<sub>2</sub>. In these distributions, the uncertainty that is explicitly characterized includes the socioeconomics and emissions projections from the RFF-SPs and the GHG concentrations and temperature changes generated from the FaIR model. Explicit characterization in these distributions of uncertain parameters in the modeling of SLR and the parametric uncertainty captured in the estimation of each damage function varies across the three damage modules.

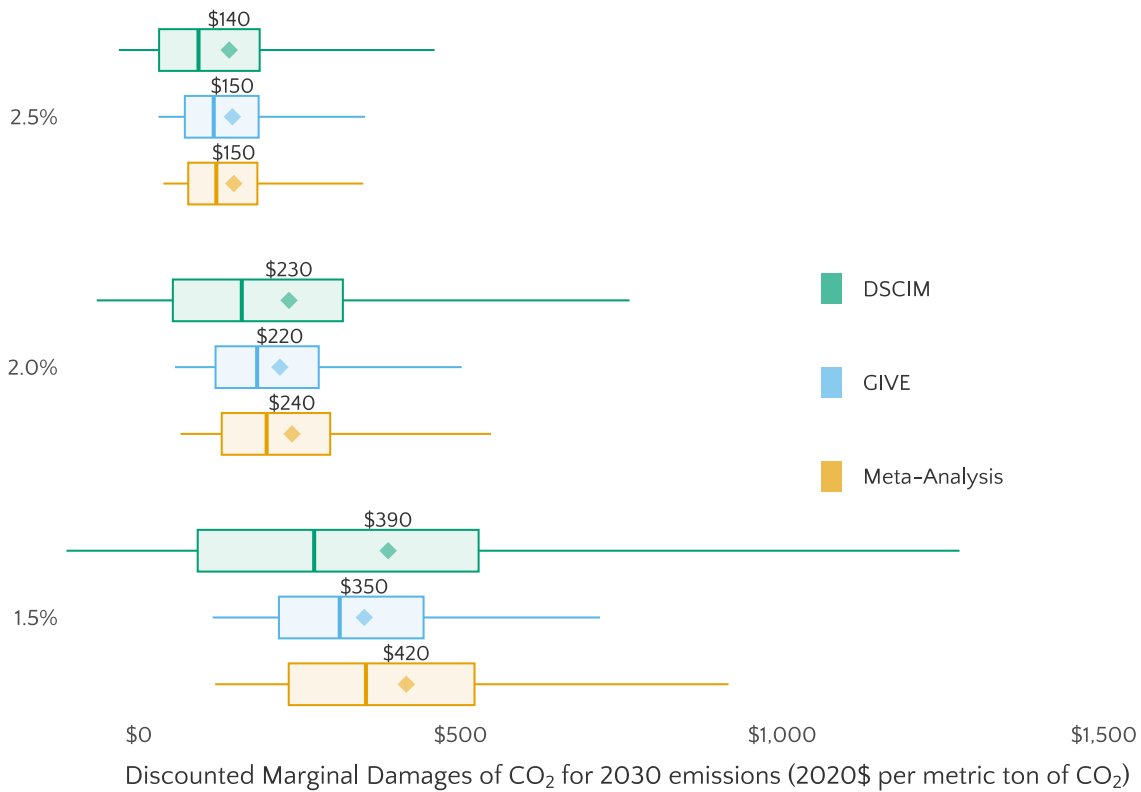
It is important to note that the distributions presented here do not fully characterize uncertainty about the SC-GHG due to impact categories omitted from the models and sources of uncertainty that have not been fully characterized due to data limitations. These limitations are discussed in Section 3.2 below.

Uncertainty grows over the modeled time horizon. Therefore, under cases with a lower near-term target discount rate – that give relatively more weight to impacts in the future – the distribution of the discounted marginal damages per metric ton of GHG is wider (see Figure 3.1.1). Across damage modules, the DSCIM based runs generate the widest distribution of results. The DSCIM damage module has a greater degree of curvature in the damage function mapping temperature to economic damages than the GIVE and meta-analysis-based specifications (see Figure 2.3.2). The interquartile ranges overlap across the three damage modules. For a presentation of the temporal evolution of the projected discounted marginal damages for GIVE see Extended Data Fig. 2 in Rennert et al. (2022b). Rennert et al. (2022b) find that for an emissions year of 2022 average discounted marginal damages increase rapidly between 2020 and 2050 and peak around 2070. After this point the increasing impact of discounting overtakes the increasing marginal damages and therefore, discounted marginal damages steadily decline through 2300.

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<sup>134</sup> Figure A.6.11 and Figure A.6.12 in Appendix A.6 shows the distribution of discounted marginal damages per metric ton for CH<sub>4</sub> and N<sub>2</sub>O.

**Figure 3.1.1: Distribution of the Discounted Marginal Damages per Metric Ton of Carbon Dioxide (CO<sub>2</sub>) for 2030 Emissions, by Near-term Ramsey Discount Rate and Damage Module**



Boxes span the inner quartile range (25<sup>th</sup> to 75<sup>th</sup> percentiles), whiskers extend to the 5<sup>th</sup> (left) and the 95<sup>th</sup> (right) percentiles. The vertical lines inside of the boxes mark the median of each distribution, and the points inside of the boxes and dollar estimates on top of the boxes mark the certainty-equivalent social cost of carbon (SC-CO<sub>2</sub>)

Table 3.1.4 provides a disaggregation of the SC-CO<sub>2</sub> results by impact category for emissions in 2030 under the GIVE and DSCIM based damage modules – alongside the meta-analysis-based damage module that does not permit a disaggregation. The GIVE and DSCIM damage modules are consistent in that net mortality risk increases are the largest share of marginal damages across the categories considered in each damage module. However, the share of marginal damages due to net mortality risk increases is larger for the DSCIM damage module compared to the GIVE damage module. Variation across the two damage modules for the other sectors reflects uncertainty in the underlying scientific literature and differences in the sectors included in the models (e.g., labor productivity). See Section 2 for detailed descriptions of the methodological differences across models. The differences in results are the aggregate effect of these different methodologies.

*Table 3.1.4: Impact Category Disaggregation of Social Cost of Carbon (SC-CO<sub>2</sub>) for 2030 under a 2.0% Near-Term Ramsey Discount Rate (in 2020 dollars per metric ton of CO<sub>2</sub>)*

| Impact category    | Damage Module |       |               |
|--------------------|---------------|-------|---------------|
|                    | DSCIM         | GIVE  | Meta-Analysis |
| Health             | \$179         | \$104 | -             |
| Energy             | -\$4          | \$10  | -             |
| Labor productivity | \$47          | -     | -             |
| Agriculture        | \$4           | \$103 | -             |
| Coastal            | \$3           | \$2   | -             |
| <i>Total</i>       | \$233         | \$219 | \$238         |

## 3.2 Omitted Damages and Other Modeling Limitations

The research community's considerable progress in developing new data and methods have helped to bring the SC-GHG estimates presented in Section 3.1 closer to the frontier of climate science and economics and address many of the National Academies' (2017) near-term recommendations. However, the SC-GHG estimates presented in this report still have several limitations, as would be expected for any modeling exercise that covers such a broad scope of scientific and economic issues across a complex global landscape. There are still many important categories of climate impacts and associated damages that are not yet reflected in these estimates due to data and modeling limitations. There is also incomplete coverage of some categories that are represented, including important sectoral and regional interactions, and feedback effects within and across modules. Table 3.2.1 below highlights some of these limitations for categories within climate and earth science, impacts and associated damages, and methodology. The table denotes those categories that the SC-GHG estimates in this report have been able to explicitly represent to some degree, those for which some share of the category is explicitly represented, and those that are not yet included at all. For example, the damage module currently focuses on climate change damages driven by changes in annual average temperatures or sea level rise. The damage modules have not yet explicitly incorporated damages associated with other changes in the temperature distribution such as variability and changes in the probability of extreme temperatures throughout the year. There is only a limited consideration of climate-driven physical changes other than temperature and SLR (such as precipitation or humidity) within the existing damage modules.

There is a literature investigating the impacts of these other climate-driven effects, including the effects of temperature variability (e.g., Estrada et al. 2023, Calel et al. 2020), of changes in rainfall levels (e.g., Damania, Desbureaux, and Zaveri 2020), and the effects of increasing rainfall variability (e.g., Downey, Lind, and Shrader 2023). Rising et al. (2022) review several dimensions of weather that will be affected by climate change. For future modeling, there are at least two potential approaches to better incorporating these climate-driven changes in variability, extremes, precipitation, and other similar metrics into the SC-GHG. The first is to examine, for example, precipitation-related impacts using multiple GCMs as inputs to damage models to characterize the range of potential relationships between global temperatures and local precipitation-driven damages. The other approach is to use a pattern-scaling approach—leveraging the high-resolution of global climate models to downscale global temperature anomalies to local ones and to use those downscaled patterns as inputs to the damage models to account for regional

heterogeneity in damages (see, e.g., Tebaldi et al. (2022)). Estimates of damages from sea level rise already account for such spatial heterogeneity by downscaling global sea level rise to local sea level rise, as described in Section 2.3.

The climate module considered in this report also omits some potentially large-scale Earth system feedback effects (e.g., from tipping elements) or non-climate mediated effects of GHG emissions (e.g., ocean acidification due to CO<sub>2</sub> emissions, tropospheric ozone formation due to CH<sub>4</sub> emissions). Climate change impacts described as resulting from tipping elements are often associated with crossing a threshold in an Earth system, or ‘tipping point’, after which a relatively small perturbation in radiative forcing results in a large, often irreversible change in the climate or other Earth systems (see, e.g., Kopits et al. (2014) for a review of this literature). Temperature feedbacks from a few of these processes (e.g., Arctic Sea ice loss, surface albedo feedback, and slowdown of the Atlantic Meridional Overturning Circulation (AMOC)) are captured in the underlying CMIP6 models to which FaIR v1.6.2 was calibrated and are thus implicitly reflected in the climate module used in this report (Weijer et al. 2020). For other processes—such as Amazon Forest dieback, melting of permafrost, changes in the Indian summer monsoon (ISM)—it is less certain how well their behavior is captured in CMIP6 models or whether their temperature impacts are implicitly included in FaIR1.6.2 (see, e.g., Arora et al. 2020, IPCC 2021d). Lastly, methane hydrates, Greenland (GIS) and Antarctic icesheet (AIS) collapse are not included at all within FaIR. However, GIS and AIS are simulated within the sea level models used in this report.

Recent studies have started to make progress on incorporating more of the tipping elements discussed above in the estimation of SC-GHG. In particular, Dietz et al. (2021b) developed a response function that maps increases in global mean surface temperature (GMST) to additional warming that is realized through feedbacks in the underlying biophysical systems such as permafrost thaw, ocean methane hydrates, Amazon rainforest dieback, surface albedo feedback, GIS and AIS collapse, the AMOC slowdown, and ISM variability. This allows for an improved, more explicit accounting of the temperature-driven damages resulting from these types of large-scale feedback effects within SC-GHG estimation. The authors find that accounting for these impacts may have substantial effects on SC-GHG estimates. For example, under their main specification Dietz et al. (2021b) estimate that the inclusion of eight individual tipping points increases the expected SC-CO<sub>2</sub> by 24.5%, characterizing a positively skewed distribution of increases to the SC-CO<sub>2</sub> (median 18.8%; 25<sup>th</sup> percentile 22.5%; 75<sup>th</sup> percentile 132.2%). Research is still needed to incorporate other physical impacts from these feedbacks, such as precipitation and ecosystem impacts associated with passing a tipping point. For example, a key missing damage channel related to the AMOC slowdown relates to changed precipitation patterns, which scientists believe would lead to additional rather than lowered damages (Liu et al. 2017). As another example, Dietz et al. (2021b) model the impacts of Amazon rainforest dieback as releasing an additional pulse of carbon. Impacts such as lost biodiversity or ecosystem services impacts associated with Amazon rainforest dieback are still absent, likely underestimating damages related to the dieback of the Amazon rainforest (Dietz et al. 2021b). The EPA will continue to follow progress in this line of research and look for opportunities to better reflect tipping elements and other Earth system feedback effects and to account for non-climate mediated GHG effects in future updates of the SC-GHG estimates. Additional discussion of some non-climate mediated GHG effects is provided in Section 3.2.2 below.

The bottom-up damage modules from the DSCIM and GIVE models provide a transparent accounting of which climate change damages are incorporated into the modules, as discussed in Section 2.3.<sup>135</sup> While the advancements in these newer damage modules is laudable, the second column of Table 3.2.1 illustrates that many categories of climate change impacts and associated damages are not yet represented. Examples include changes in the demand for water resources; the costs and feasibility of providing safe drinking water; biodiversity loss; changes in ecosystem services, the productivity of the livestock, aquaculture, and forestry industries; and loss of culturally and historically significant resources<sup>136</sup> just to name a few. Efforts are underway to incorporate existing research on these types of climate impacts into global damage functions that can be added to a damage module for SC-GHG estimation. For example, a recent study of biodiversity losses found that updating the species loss function and its valuation in FUND 3.9 (to reflect Brooks and Newbold (2014), as well as a species loss meta-analysis by Urban (2015), and updated WTP survey results) increased the SC-CO<sub>2</sub> for 2010 by about \$10/mtCO<sub>2</sub> (1995 dollars), or 20%, relative to the SC-CO<sub>2</sub> resulting from the original FUND3.9 specification (under a Ramsey discount rate of ~3%) (Kaushal and Navrud 2022). EPA continues to follow advances in the development of global damage functions for biodiversity loss and other damage categories not yet represented.

For those damage categories that are represented, they may only be a partial accounting. For example, the estimated health damages in GIVE and DSCIM only include temperature- and SLR-related mortality, and exclude other sources of mortality impacts (e.g., climate-mediated changes in storms, wildfire, air pollution), and morbidity impacts (e.g., infectious diseases, malnutrition, allergies). Studies are available on how climate-related changes impact infectious diseases (Levy et al. 2016, Trinanes and Martinez-Urtaza 2021, Colón-González et al. 2021, Ryan et al. 2019, Ryan et al. 2015, Mordecai et al. 2020), but additional work is needed to both model meteorological conditions (e.g., humidity, precipitation patterns, length of transmission seasons, and daily temperature ranges) under climate change and link these to infectious disease damage functions (Cromar et al. 2022). Regarding sea level rise, the represented damages do not fully include channels such as salt-water intrusion and its impact on the agriculture sector, coastal recreation, and tourism, an increase in the frequency or intensity of storm surge events (Grinsted et al. 2013), and compounding impacts of storm surge and wind damage that often come with cyclones and hurricanes (Diaz 2016). Importantly, none of the damage modules incorporate cross-country or regional spillovers that occur through migration, national security concerns, tourism, or supply chain disruptions. The physical and economic pathways that drive many of these omitted or partially included categories are well documented in key scientific assessments, such as those developed by the IPCC (e.g., IPCC 2007a, 2014a, 2018, 2019a, 2019b, 2021a) and the U.S. Global Change Research Program (e.g., USGCRP 2016,

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<sup>135</sup> For the GIVE model, Rennert et al. (2022b) illustrate the impact that the updated damage functions have on the SC-CO<sub>2</sub> estimates relative to damages functions used in earlier studies. The authors find the SC-CO<sub>2</sub> estimate is notably larger when using GIVE's updated four-sector damage function (\$185/mtCO<sub>2</sub> in 2020 under 2% Ramsey discounting compared to using the aggregate top-down damage function approach used in the 2016 version of the DICE model (\$152/mtCO<sub>2</sub> in 2020), which was stated to be more comprehensive in scope and included a 25% adder for omitted impacts (holding all else equal in the modeling).

<sup>136</sup> The National Academies (2017) highlighted “loss of cultural heritage, historical monuments, and favored landscapes” among examples of potentially important nonmarket welfare consequences of climate change. For discussion of many U.S. historic sites and landmarks at risk from climate change, see, for example, Holtz et al. (2014), and the Fifth National Climate Assessment (USGCRP 2023) (including the Overview (Jay et al. 2023) and Human Health chapter (Hayden et al. 2023)).

2018a, 2023). However, key data and research gaps currently prevent incorporating these damage categories into global damage modules for the purpose of estimating the SC-GHG.

Finally, while the SC-GHG estimates presented in this report provide numerous methodological improvements over the previous estimates, as detailed in Section 2, Table 3.2.1 highlights that there are also opportunities for future improvements. For example, although the damage functions applied in this report offer an improved accounting of adaptation and its costs, the modeled estimates employ optimistic assumptions about adaptation decisions in the estimation of coastal damages in GIVE and DSCIM. As discussed in Section 2.3, the representation of adaptation and its costs in both models are based on the CIAM deterministic optimization model assumes decision makers have perfect foresight about SLR conditions throughout the model time horizon and always choose the lowest-cost adaptation strategy and level of investment for each of the thousands of coastal segments (Diaz 2016). Within the models, local segment level decisions are made without considering spillovers or interactions across segments, nor the likely impact one segment's decision may have on a neighboring segment (e.g., Dundas and Lewis 2020). Recent studies have also highlighted that observed levels of investment in adaptive measures are significantly lower than what is predicted under optimistic cost-minimizing assumptions (e.g., Bakkensen and Mendelsohn 2016, Mendelsohn et al. 2020). Researchers have started to examine how sub-optimal decisions could impact aggregate economic costs to society from sea level rise and storm surge flooding in the U.S. (e.g., Lorie et al. 2020). Oppenheimer (2021) describes many of the current limitations and challenges of adaptation in a U.S. context, particularly that current adaptation policy tends to be implemented reactively, post-disaster. The costs of such a reactive, piecemeal strategy may differ substantially from the costs of a coordinated and proactive adaptation strategy. The modeling of future adaptation and its costs are an important area of future research for other damage categories as well. For example, even the empirically based estimation of revealed adaptation for other damages in DSCIM must rely on what has been observed in the historical record. It remains challenging to project how the costs of adaptation will increase at higher levels of warming and potential increases in the intensity of extreme events, and how quickly technological advances could help to work in the other direction to reduce the costs of adaptation investments or provide new adaptation alternatives.

Another important methodological limitation of the SC-GHG estimates presented in this report is the omission of many interactions and feedback effects within and across modules. Regarding feedback effects within the damage module, none of the models explicitly consider potential interactions among damage categories. For example, there is no representation of how climate change-mediated impacts to water supply will interact with climate-mediated changes in the demand for water resources by the agricultural and electric power sectors, which might be in direct competition with each other in similar water markets. Large cross-disciplinary multisector dynamic modeling efforts are well underway in the U.S. to advance the understanding and modeling of such interactions, especially with respect to growing interdependencies and risks at the intersection of the energy, water, and land sectors (Reed et al. 2022). Regarding feedbacks within the climate module, while the FaIR model does include a representation of some carbon cycle feedbacks (Smith et al. 2018), other greenhouse gas feedbacks such as the response of natural methane emissions to temperature are less well represented (e.g., Dean et al. 2018, Colbert et al. 2020, Röbger et al. 2022, Zhang et al. 2023). Ongoing research is improving the characterization of these feedbacks in reduced complexity models (e.g., Woodard et al. 2021).



In addition, this update does not account for feedbacks across modules, such as feedbacks from damages to the socioeconomics module, or from the climate module to human emissions (Beckage et al. 2018, Beckage et al. 2020, Peng et al 2021, Moore et al. 2022). Cross-module feedback effects can result through a variety of physical and behavioral responses. Some feedbacks are likely to occur in absence of a policy response. For example, the modeling in this report does not account for how energy system impacts (such as increased use of air conditioning) will affect emissions pathways (e.g., Woodard et al. 2019). As another example, similar to the potential feedbacks from the passing of critical earth system tipping points discussed above, there is the possibility of nongradual damages from passing thresholds in socioeconomic systems (e.g., climate driven self-reinforcing feedback cycle of civil conflict and slow or negative economic growth) (National Academies 2017). Other feedbacks between the damages and socioeconomics modules arise endogenously from the coupled interaction of the climate, social, political and energy systems. For example, Moore et al. (2022) review the breadth of literature that examines responses in social and political systems to calibrate a modified version of DICE 2016 that includes a variety of potential feedbacks between the climate and socioeconomics modules. These feedbacks across modules include a range of social perceptions, opinions, political systems, legal systems, endogenous cost (learning-by-doing), and potential feedbacks related to energy demand and economic growth due to changes in temperature (e.g., Dell et al. 2012, Burke et al. 2015, and Woodard et al. 2019). Conditional on the feedbacks they included in their model, they find that accounting for feedbacks between the climate and socioeconomics modules (e.g., changing behavior in response to experienced or observed climate change) could result in a reduction in overall GHG emissions relative to a no-feedback (business as usual) world. While the RFF-SPs used within this report take into account the likelihood of future emissions mitigation policies and technological developments (Section 2.1), which implicitly capture the feedbacks explored in Moore et al (2022), the National Academies (2017) identified explicitly accounting for feedbacks between the damages and climate modules to the socioeconomic module as an important longer-term goal in the SC-GHG estimation process.

The methodologies in this report incorporate many major advances in the treatment of uncertainty in integrated assessment modeling (see Appendix A.8 and Table A.8.1 for a summary and further discussion). However, there remain several sources of uncertainty that have not yet been quantified and are thus not represented in the SC-GHG estimates presented in this report. For example, as discussed in Section 2.3.2, the Monte Carlo estimation in GIVE reflects the damage uncertainty in the health and agriculture impact categories, but not the energy and coastal categories due to data limitations. Similarly, DSCIM's Monte Carlo sampling of dose-response parameters is performed for the health, agriculture, energy, and labor impact categories but not the coastal category due to data limitations.

Equally important to note among the methodological limitations is the valuation of risk aversion in the updated SC-GHG estimates. As noted in Section 2.5, the SC-GHG estimates provide an improved accounting of risk aversion over the estimates used in the EPA's analyses to date. However, the approach relies on an isoelastic utility function in which a single parameter has a role in reflecting both intertemporal and risk preferences. In this report, the utility function parameter is calibrated based on its role representing intertemporal preferences leading to lower values than would be expected if it was calibrated based on its role representing risk preferences. As a result, the SC-GHG estimates likely underestimate the damages associated with increased climate risk resulting from a marginal ton of emissions, all else equal. As noted in Section 2.5, to address this calibration challenge, some recent SC-

GHG studies have used alternative utility function specifications (e.g., Epstein-Zin specifications) that allow for the separation of intertemporal and risk preferences (Cai et al. 2016, Daniel et al. 2019, Cai and Lontzek 2019, Okullo 2020, Lemoine 2021, Van den Bremer and Van der Ploeg 2021).

Although not all omitted climate change impacts work in the same direction in terms of their influence on the SC-GHG estimates, taken together, the numerous damage categories that cannot currently be included due to data limitations, modeling assumptions that go in the direction of being a partial representation of included damage categories, and other limitations discussed above and throughout Section 2, make it likely that the SC-GHG estimates presented in this report underestimate the marginal damages from GHG emissions. For example, first, as discussed above, many categories of damages are only partially modeled or omitted altogether in the DSCIM- and GIVE-based damage modules. Second, many interactions and feedback effects are not yet represented, both in modeling physical Earth system changes (e.g., feedback effects of tipping elements) and economic damages. For the GIVE model-based results, Rennert et al. (2022b) “expect that, in total, the future inclusion of additional damage sectors and tipping elements is likely to raise the estimates of the SC-CO<sub>2</sub>, and that therefore the estimates from the present study are likely best viewed as conservative.” Third, as noted in Section 2.3, data limitations have been pointed out as a likely cause of the estimated response function in DSCIM to underestimating mortality risk increases in some low-income regions. Fourth, under the meta-analysis-based damage module, the results are based on a Howard and Sterner (2017) specification to which those authors and other researchers (e.g., Nordhaus and Sztorc 2013, Nordhaus 2017) have routinely added a generic 25% increase in recognition of omitted damages that are likely significant. Fifth, coastal damages in both GIVE and DSCIM are estimated based on an optimistic assumption that optimal, lowest cost adaptation opportunities will be realized globally under perfect foresight about SLR. Sixth, the estimates do not incorporate the potential for climate damages to have a persistent economic impact through an effect on economic growth. Finally, the method employed to account for risk aversion likely underestimates the damages associated with increased climate risk resulting from a marginal ton of emissions.

Table 3.2.1: Climate and Earth Science, Impacts, and Damages Included in the Updated SC-GHG Estimates

| Climate and Earth Science                                                                                | Impacts and Associated Damages                                                                                                        |
|----------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| <b>Temperature change</b>                                                                                | <b>Human Health and Well-being</b>                                                                                                    |
| Averages                                                                                                 | Heat and cold related mortality                                                                                                       |
| Extremes                                                                                                 | Mortality and morbidity from extreme weather events (e.g., storms, wildfire, flooding), and sea level rise                            |
| Variability                                                                                              | Mortality and morbidity from climate mediated changes in the formation of criteria air pollutants (e.g., ozone, PM2.5)                |
| <b>Sea level rise</b>                                                                                    | Infectious diseases                                                                                                                   |
| From average temperature change                                                                          | Other morbidity (e.g., malnutrition, allergies)                                                                                       |
| Non-linear effects (e.g., ice-sheet collapse)                                                            | Displacement and migration                                                                                                            |
| <b>Precipitation</b>                                                                                     | <b>Labor</b>                                                                                                                          |
| Averages                                                                                                 | Labor supply (i.e., hours worked)                                                                                                     |
| Extremes                                                                                                 | Labor productivity (i.e., output per hour worked)                                                                                     |
| Variability                                                                                              | <b>Energy</b>                                                                                                                         |
| <b>Humidity – wet-bulb temperature</b>                                                                   | Energy consumption (e.g., heating, cooling)                                                                                           |
| <b>Additional impacts from large scale Earth system changes (tipping elements, etc.)</b>                 | Energy production and provision (e.g., hydroelectric, thermal power generation)                                                       |
| Temperature                                                                                              | <b>Water</b>                                                                                                                          |
| Sea level rise                                                                                           | Water consumption (residential, industrial, commercial)                                                                               |
| Precipitation                                                                                            | Provision of safe drinking water                                                                                                      |
| Extreme weather events                                                                                   | Water storage and distribution                                                                                                        |
| Ecosystems                                                                                               | <b>Land</b>                                                                                                                           |
| Other impacts                                                                                            | Coastal land loss from sea level rise                                                                                                 |
| <b>Non-climate mediated effects (e.g.)</b>                                                               | <b>Buildings, transportation, and infrastructure</b>                                                                                  |
| Carbon fertilization (CO <sub>2</sub> )                                                                  | Sea level rise                                                                                                                        |
| Ocean acidification (CO <sub>2</sub> )                                                                   | Intensity or frequency of coastal storms                                                                                              |
| Tropospheric ozone formation (CH <sub>4</sub> )                                                          | Extreme weather inland (e.g., storms, wildfire, flooding)                                                                             |
| Stratospheric ozone destruction (N <sub>2</sub> O)                                                       | Environmental conditions (e.g., melting permafrost, air temperature and moisture)                                                     |
|                                                                                                          | <b>Food production</b>                                                                                                                |
| <b>Methodology</b>                                                                                       | Agriculture/Crop production                                                                                                           |
| Explicit treatment of uncertainty                                                                        | Animal and livestock health and productivity                                                                                          |
| Accounting for adaptation and costs of adaptation                                                        | Fisheries and aquaculture production                                                                                                  |
| Interactions across sectors                                                                              | <b>Forestry</b>                                                                                                                       |
| Feedbacks across modules (e.g., from damages to socioeconomics and emissions, from climate to emissions) | Timber, pulp, and paper production                                                                                                    |
| Valuation of risk                                                                                        | <b>Tourism, recreation, aesthetics, culturally historic sites</b>                                                                     |
|                                                                                                          | Visitation, locations, and opportunities (e.g., recreational fishing, skiing, scuba diving, scenic views)                             |
|                                                                                                          | <b>Ecosystem services</b>                                                                                                             |
|                                                                                                          | Availability and quality of natural capital used in the production of marketable goods                                                |
|                                                                                                          | Biodiversity and wildlife habitat (e.g., aquatic environments, breeding grounds)                                                      |
|                                                                                                          | Other provisioning and regulating services (e.g., water filtration, wildfire/flood/pest mitigation, medicinal resources, pollination) |
|                                                                                                          | <b>Culturally and historically significant landmarks and resources</b>                                                                |
|                                                                                                          | <b>Crime (property, violent)</b>                                                                                                      |
|                                                                                                          | <b>National Security</b>                                                                                                              |
|                                                                                                          | Military base impacts                                                                                                                 |
|                                                                                                          | Military mission impacts from international civil conflict                                                                            |
|                                                                                                          | International development, humanitarian assistance                                                                                    |
|                                                                                                          | <b>Trade and logistics</b>                                                                                                            |
|                                                                                                          | Supply chain disruption (e.g., from extreme weather)                                                                                  |
|                                                                                                          | Supply chain transitions (e.g., altering trade routes)                                                                                |

**Legend**

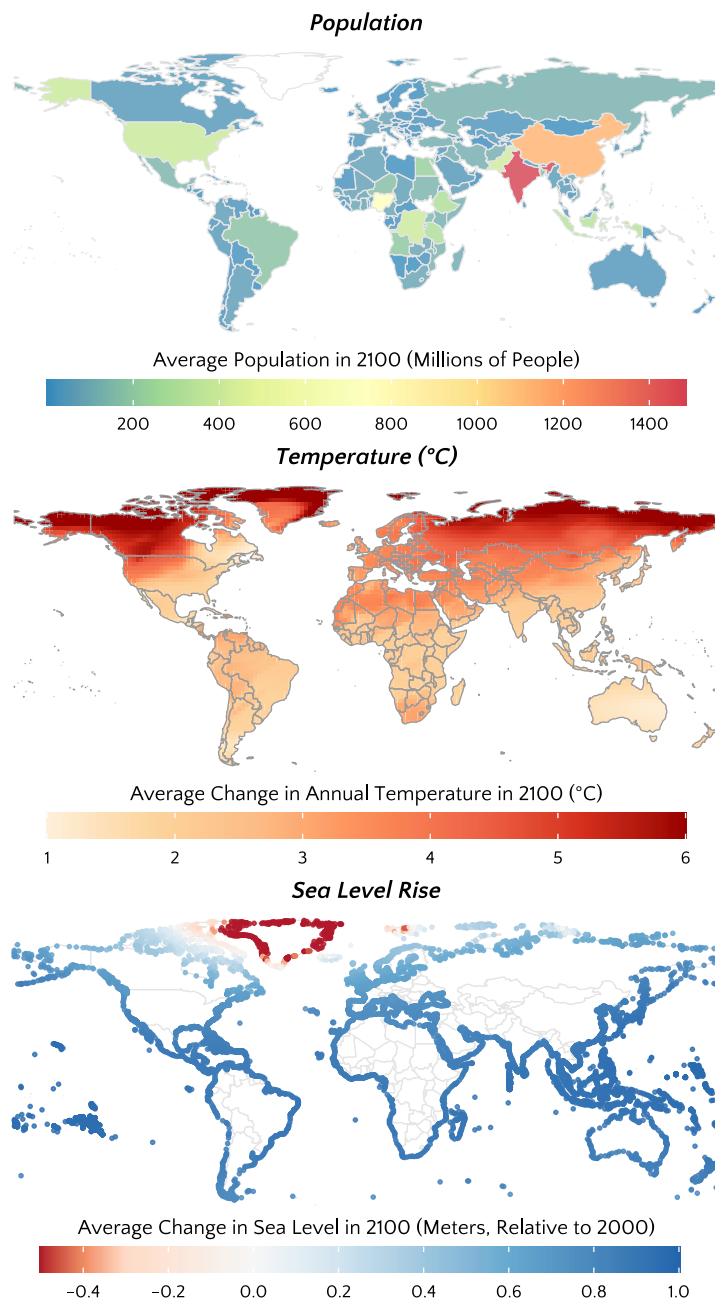
- Explicit Representation
- ◐ Partial or Implicit Representation
- Not Yet Incorporated

Table 3.2.1 presents a general indication of the climate science, impacts, and damages included across the three damage modules used in this analysis and is not designed to be reflective of any one specific damage module.

One way to illuminate the potential magnitude of some omitted damage categories is to consider the current spatial distribution of global population and climate indicators. Figure 3.2.1 shows that a substantial portion of the world's population lives in latitudes that are projected to experience some of the highest temperatures. And although not explicitly captured in the figure, within each country, most of these populations are located near the coasts in areas expected to experience significant sea level rise. The spatial correlations that exist between population centers and known damage pathways highlight how temperature- and SLR-related damages will impact a significant share of the world's population. This further underlines the significance of impacts not currently reflected in the estimates, such as geopolitical and regional tensions, conflict, scarcity, displacement, and migration, all of which are issues that affect an interconnected global economy.

### 3.2.1 Further Discussion of Precipitation Impacts of Climate Change

Figure 3.2.1: Population, Temperature, and Sea Level Rise in 2100



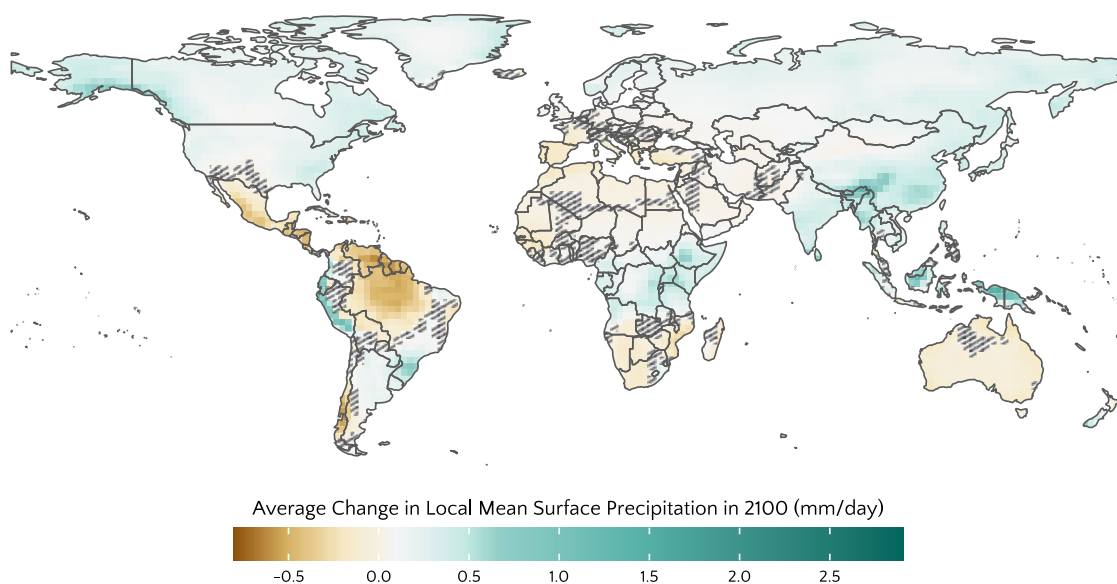
Estimates of average country-level population come from the RFF-SPs (top). Average changes in local mean surface temperature are recovered using a pattern scaling approach (EPA 2023), summarized within 2-degree grid cells (middle). Average change in sea-level rise comes from the over 12,000 individual segments underlying CIAM (bottom). Averages are taken across the 10,000 Monte Carlo simulations of the model for the year 2100.

As discussed above, the damage modules used to estimate the SC-GHG in this report focus on climate change damages driven by changes in average annual temperatures (GMST) or sea level rise (GMSL). While some of the underlying damage studies incorporate other climate variables, such as precipitation or local temperatures, to inform the shape of the dose-response curves in each impact category, the damage modules themselves do not explicitly take projections of climate variables other than temperature as inputs when estimating the SC-GHG. That is, GMST is the only input required to run each of the three damage modules—acting as a sufficient statistic for other correlated climate variables. Therefore, the damage modules only reflect very limited representations of the market and non-market damages resulting from climate-mediated impacts to precipitation and other key water cycle characteristics. As noted in the most recent IPCC report from AR6, WG1 (IPCC 2021a, 2021f, 2022), while annual mean global land precipitation is expected to increase over the 21<sup>st</sup> century, the total land area subject to drought is also expected to increase, become more frequent, and more severe. These IPCC assessments summarize annual mean changes in precipitation, but the variability and extremes of precipitation events are also expected to worsen. An area for future research is the development of global damage functions that can explicitly account for expected changes

in mean precipitation, its variability, and its extremes.

Some recent work has used pattern scaling to translate estimated changes in GMST, such as those projected by FaIR, to local changes in local temperature and local precipitation (Lynch et al. 2017, Kravitz and Snyder 2023). This approach takes spatially resolved changes in climate variables as estimated by more computationally intensive and complex GCMs, that rely on only a small subset of possible warming futures, to derive a relationship between GMST and local climate variables. The resulting relationship (the “pattern”) can then be applied to a broader range of GMST projections.<sup>137</sup> Figure 3.2.2 presents the projected change in local mean surface precipitation in 2100 resulting from a pattern scaling approach. The figure applies the estimates of GMST in the year 2100 coming out of the FaIR climate module, as described in Section 2.2, to the expected changes in annual local mean surface precipitation from 26 GCMs (CMIP6) under a single warming scenario (SSP2-RCP4.5) to recover average local changes in annual precipitation from 10,000 possible warming futures. Such an approach allows for a much broader exploration of the effects of changes in precipitation without requiring all 10,000 emissions scenarios to be run through large-scale GCMs. Pattern scaling GMST to recover changes in local precipitation could allow for the inclusion of damage functions that explicitly incorporate changes in local precipitation to inform estimates of the SC-GHGs.

*Figure 3.2.2: Changes in Local Mean Surface Precipitation in 2100*



*Changes in local mean surface precipitation are recovered using a pattern scaling approach (EPA 2023). Averages are taken across the 10,000 Monte Carlo simulations of the RFF-SPs and FaIR1.6.2, and the patterns underlying the 26 GCMs (Kravitz and Snyder 2023). Patterns are summarized within 2-degree grid cells. Hatched grid cells represent areas with large variation across the 26 GCMs (i.e., the standard deviation is larger than seven times the mean).*

<sup>137</sup> See <https://github.com/usepa/pattern-scaled-climate-variables> for more details on pattern scaling approaches being developed for use in probabilistic integrated assessment models.

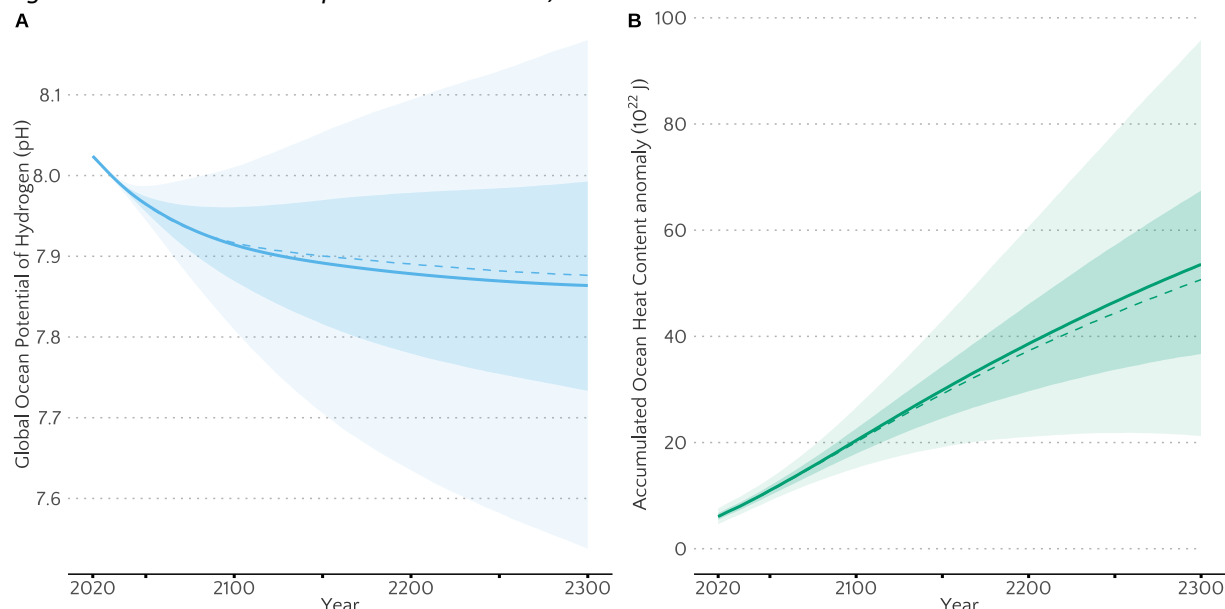
### 3.2.2 Further Discussion of Ocean Acidification and Other Non-Climate Mediated Impacts of GHG Emissions

SC-GHG estimation to date has primarily focused on the climate-mediated effects: e.g., the pathway from emissions, to concentration, to radiative forcing, to temperature, to climate change, and to economic damages. However, there are other impacts of GHG emissions. The only non-climate-mediated effect included in SC-GHG estimates to date and those in this report is the crop fertilization effects resulting from elevated CO<sub>2</sub> concentrations.

However, there are several other potentially important non-climate-mediated GHG effects. These include, for example, the ecosystem effects of ocean acidification and aragonite undersaturation resulting from elevated concentrations of CO<sub>2</sub>, the health and agricultural impacts of tropospheric ozone generated through chemical conversion of methane in the atmosphere, and the health effects of stratospheric ozone destruction resulting from elevated concentrations of N<sub>2</sub>O. Several studies have investigated these effects and are discussed here.

***Ocean acidification from carbon dioxide (CO<sub>2</sub>) concentrations.*** In addition to its effects on temperature and other climate endpoints, CO<sub>2</sub> emissions contribute to ocean acidification, which will likely result in substantial changes to marine ecosystems. The ocean absorbs about 30% of the CO<sub>2</sub> released into the atmosphere. Higher atmospheric levels of CO<sub>2</sub> cause the ocean to absorb more, which affects the carbonate chemistry of seawater. Water and carbon dioxide combine to form carbonic acid, contributing to ocean acidification (i.e., the pH decreases, and the ocean becomes more acidic). As noted in Section 2.2, the FaIR reduced complexity climate model calculates carbon dioxide uptake in the world's ocean as part of its carbon cycle calculation and provides projections of pH and ocean heat uptake. Specifically, the model estimates the changes in pH with a simple function to approximate globally averaged surface ocean pH from atmospheric CO<sub>2</sub> concentrations (National Academies 2017) and accounts for uncertainty in the atmospheric CO<sub>2</sub> concentrations. Figure 3.2.3 depicts the range of ocean pH (Panel A) and ocean heat (Panel B) that is predicted by the coupling of the RFF-SPs with FaIR1.6.2. Under these projections, mean ocean pH is expected to decrease by 0.11 pH units by 2100 relative to 2020.

**Figure 3.2.3: Global Ocean pH and Ocean Heat, 2020-2300**



*Uncertainty is represented by the emissions uncertainty from the RFF-SP projections and physical climate uncertainty from Fair1.6.2. Mean (solid) and median (dashed) lines along with 5<sup>th</sup> to 95<sup>th</sup> (dark shade) and 1<sup>st</sup> to 99<sup>th</sup> (light shade) percentile ranges.*

One of the impacts of ocean acidification is a reduction in the concentration of carbonate ions available to calcifying marine organisms to build and maintain skeletons, shells, and other carbonate structures. Among the affected organisms are mollusks, bivalves, reef building corals, and microorganisms at the base of the marine food web. Commercially valuable shellfish including oysters, clams, and abalone exhibit reduced growth and survival rates under conditions expected by mid-century (Ries et al. 2009). The synergistic effects of marine heatwaves and acidification on coral reefs will inhibit corals' ability to recover from increasingly frequent bleaching events (Klein et al. 2022). The scale of follow-on effects of ocean acidification on marine ecosystems (including fisheries) resulting from a reduced availability of habitat and prey is much more uncertain and difficult to quantify.

Studies estimating the economic impacts of ocean acidification necessarily focus on those for which the biophysical outcomes are best understood. Several studies forecast producer and consumer welfare losses in commercial shellfish markets in the US (Cooley and Doney 2009, Cooley et al. 2015, Moore 2015), in Europe (Fernandes et al. 2017, Narita and Rehdanz 2017), and globally (Narita et al. 2012). Some of the largest forecasted welfare impacts of ocean acidification arise from the recreational and existence value of coral reefs (Brander et al. 2012, Lane et al. 2013) while other studies include the impacts of lost coral reef habitat on finfish (Colt and Knapp 2016, Kite-Powell 2009, Speers et al. 2016). Finally, ocean acidification and the loss of coral reefs may increase coastal flood damages. Coral reefs provide a natural defense against coastal erosion and storm surges by dissipating an average of 97% of wave energy (Ferrario et al 2014). The impacts of ocean acidification are not included in the damage modules used in this report because work remains to upscale existing regional studies to capture global economic impacts. Among the challenges is accounting for synergistic effects between temperature and seawater chemistry and how the ecological impacts differ across economically important species. With the current



understanding of pH and temperature effects on growth and survival of shellfish and corals, and existing market and nonmarket valuation data for the ecosystem services they provide, we expect that it will be feasible to develop damage functions for some ocean acidification impacts in future SC-GHG updates.

***Tropospheric ozone formation from methane (CH<sub>4</sub>) emissions.*** In addition to its climate effects, methane oxidation in the atmosphere leads to the production of tropospheric ozone, which has harmful effects for human health and plant growth (USGCRP 2018c). Due to methane's atmospheric perturbation lifetime of about 12 years (IPCC 2021e), methane is well-mixed globally and therefore the effects on ozone are also global (in contrast to regional ozone effects from NO<sub>x</sub> and VOC emissions). Studies have estimated that half of the increase in global annual mean ozone concentrations since preindustrial times is due to anthropogenic methane emissions (IPCC 2013).

McDuffie et al. (2023) present the most recent estimate of the health risks associated with the methane-ozone impact mechanism. Using the same socioeconomic projections, mortality risk valuation, and discounting approaches described elsewhere in this report, McDuffie et al. (2023) find the monetized increase in respiratory-related human mortality risk from the ozone produced from methane emissions in 2020 to be \$1800 per ton of CH<sub>4</sub> (95% confidence interval: \$760-2800/mtCH<sub>4</sub>).<sup>138</sup> These results are similar to an earlier study by Sarofim et al. (2017) who estimated a net present damage (2020\$) of \$900 to \$2100 per ton of CH<sub>4</sub> emissions in 2020, using a methodology similar to that of the IWG SC-GHG estimates at the time the paper was written. A 2021 study conducted by the United Nations Environment Programme (UNEP) and Climate and Clean Air Coalition (CCAC) estimated that sustained reductions of a million tons of methane emissions per year could prevent about 1,430 premature deaths annually, along with preventing the loss of 145,000 tons of wheat, soybeans, maize and rice (UNEP 2021). The UNEP report's mortality results are larger than both the McDuffie et al. (2023) and Sarofim et al. (2017) estimates of deaths avoided due to the mitigation of a million tons of methane (760 and 239-591 deaths, respectively). However, UNEP also included an estimate of the additional cardiovascular mortality risk due to elevated ozone concentrations. Collectively, these studies suggest that the methane-ozone impact mechanism is associated with additional human health-related, non-climate mediated damages that are not currently accounted for in the partial SC-CH<sub>4</sub> values presented in this report.

***Stratospheric ozone destruction from nitrous oxide (N<sub>2</sub>O) emissions.*** In addition to its climate effects, N<sub>2</sub>O has impacts on stratospheric ozone. When N<sub>2</sub>O is in the stratosphere, high-energy photons break it apart resulting in the production of nitric oxide (NO). Like the chlorine atoms from CFCs, NO can catalytically destroy ozone. Because of this reaction, it has become clear that as CFC emissions are eliminated, N<sub>2</sub>O emissions have become the largest anthropogenic contributor to the destruction of stratospheric ozone (Ravishankara et al. 2009, Portmann et al. 2012, WMO 2018). A recent article (Kanter et al. 2021) estimated the monetized impacts of the stratospheric ozone loss due to N<sub>2</sub>O emissions on human health

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<sup>138</sup> McDuffie et al. (2023) present global and country-specific net present damages associated with respiratory-related mortality attributable to exposure to ozone from methane emissions in the year 2020. Using the same methodology to calculate the net present damages associated with 2030 methane emissions yields a marginal damage estimate of \$2400 per ton of CH<sub>4</sub>.

and crop damages as \$2,000 per ton N<sub>2</sub>O (2020 dollars)<sup>139</sup>, or over 11% of the value of the SC-N<sub>2</sub>O estimate for 2020 emissions in the IWG February 2021 TSD.

**Other effects.** As discussed in Section 2, the SC-GHG estimates presented in this report include the monetized value of carbon dioxide fertilization effects on agriculture. There may be additional benefits of carbon dioxide fertilization for ecosystems. However, elevated CO<sub>2</sub> concentrations can also lead to reductions in the nutrient content (such as protein, iron, and zinc) of some crops, with potential negative effects on diets (Beach et al. 2019). Elevated CO<sub>2</sub> concentrations can also change the production and allergenicity of aeroallergens (Ziska, 2020). These additional impacts have not been monetized.

One approach for accounting for non-climate mediated GHG effects in SC-GHG estimates would be to use the estimates of the dollar impacts of a ton of emissions of a given gas from existing studies and add those impacts to the appropriate social cost. Another approach would be to estimate the monetized damages within the existing SC-GHG modeling framework. For example, as recommended in Kanter et al. (2021), this might involve estimating the change in stratospheric ozone concentrations over time resulting from an additional ton of N<sub>2</sub>O emissions, and then calculating the increase in the risk of health effects resulting from the increased ozone concentration (e.g., skin cancer morbidity and mortality). The health effects can then be valued within the framework in the same way that mortality resulting from extreme heat events or other climate effects is valued.

### 3.3 Distribution of Modeled Climate Impacts

As discussed in detail in Section 1, benefit-cost analysis of Federal regulations and other actions include the global net damages from expected changes in GHG emissions. The distinctive global nature of GHG emissions combined with an increasingly interconnected world means that climate change impacts occurring on one side of the world can directly and indirectly affect the welfare of citizens and residents of a country located on the other side of the world through a multitude of pathways. As the prominent 2014 CNA study concluded, the increasing political complexity and economic integration across the world makes it “no longer adequate to think of the projected climate impacts to any one region of the world in isolation. Climate change impacts transcend international borders and geographic areas of responsibility” (CNA 2014).

However, there is heterogeneity in the distribution of climate change damages across the globe and within the U.S. The SC-GHG by design, and consistent with the economic theory and methods for benefit-cost analysis, is an aggregation across individuals of their willingness to pay to avoid the marginal damages of climate change. As such, the SC-GHG is not designed to characterize the many important distributional considerations of climate change damages.<sup>140</sup> Therefore, it is important for the results of analyses using

<sup>139</sup> Kanter et al. (2021) estimate a median value of US\$2.66 per kg N<sub>2</sub>O–N (in 2008 dollars) for the ozone impacts of N<sub>2</sub>O emissions. We convert this estimate to \$/ton N<sub>2</sub>O using the N<sub>2</sub>O–N to N<sub>2</sub>O factor of 1.57 and adjust for inflation to 2020 dollars using the annual GDP Implicit Price Deflator values in the U.S. Bureau of Economic Analysis (BEA) NIPA Table 1.1.9 (BEA 2023b) (specifically, using 2020USD = 2008USD x (113.648 / 94.419)).

<sup>140</sup> Some analysts (e.g., Azar and Sterner 1996, Anthoff et al. 2009, Anthoff and Emmerling 2019) employ “equity weighting” to incorporate distributional equity objectives into estimates of the SC-GHG. As noted by Anthoff and Emmerling (2019), “[e]xisting equity weighting studies assume a social welfare function (SWF) that exhibits inequality aversion over per capita consumption levels.”

the SC-GHG to be placed in context with respect to how the impacts of climate change are expected to be distributed across regions and populations. This section presents the available evidence on the distribution of climate change impacts based on the results from the SC-GHG modeling above, and also includes a discussion of related published literature.

The spatial distribution of climate impacts is the result of complex physical and economic dynamics interacting with the existing heterogeneity in physical and socioeconomic conditions. As discussed at length in Section 2.3 and emphasized in Section 3.2, the damage modules used in this report do not capture all of the pathways through which climate change affects public health and welfare and hence only cover a subset of potential climate change impacts. Furthermore, the damage modules do not explicitly capture spillover or indirect effects whereby climate impacts in one country or region can affect the welfare of residents in other countries or regions, as detailed in Section 1.3.<sup>141</sup> Two of the models used to inform the damage module in this report, the DSCIM and GIVE models, have spatial resolution that allows for some geographic disaggregation of future climate impacts across the world. Hence, the results from the SC-GHG modeling in this report are only able to provide partial evidence of the global distribution of climate change impacts.

Conditional on these critical caveats, the spatial resolution in both models does allow for the calculation of a partial SC-GHG measuring the damages from climate impacts physically occurring within a particular country. For example, the DSCIM damage module, which includes net impacts on temperature-related mortality, agriculture, energy expenditures, labor productivity, and sea level rise, estimates damages from that subset of climate change impacts physically occurring within the U.S. of \$14 per mtCO<sub>2</sub> for a 2030 emissions year, rising to \$27 per mtCO<sub>2</sub> for a 2080 emissions year (under a near-term target discount rate of 2%).<sup>142</sup> The GIVE damage module, which includes net impacts on temperature-related mortality, agriculture, energy expenditures, and sea level rise, estimates damages from that subset of climate change impacts physically occurring within the U.S. of \$16 per mtCO<sub>2</sub> for 2030 CO<sub>2</sub> emissions, rising to \$24 per mtCO<sub>2</sub> for 2080 CO<sub>2</sub> emissions (under a near-term target discount rate of 2%).<sup>143</sup>

These estimates are not equivalent to an estimate of the benefits of marginal GHG mitigation accruing to U.S. citizens and residents, even for the 4-5 damage categories included in GIVE and DSCIM. First, due to technical modeling limitations these estimates do not include damages from physical impacts occurring in all U.S. territories. For example, damages occurring in Guam, a U.S. territory that is already being affected by climate change, are not captured in these estimates. As highlighted in a recent DoD report, “[a]t Naval Base Guam, recurrent flooding limits capacity for a number of operations and activities including Navy Expeditionary Forces Command Pacific, submarine squadrons, telecommunications, and a number of other specific tasks supporting mission execution” (DoD 2019). Second, for the reasons discussed in Section 1, these estimates exclude the myriad of pathways through which global climate impacts directly and indirectly affect the interests of U.S. citizens and residents. As discussed more in Section 1, U.S. citizens and residents live, own property, own investments, travel, and have familial,

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<sup>141</sup> The one exception is that the agricultural damage function in DSCIM and GIVE reflects the ways that trade can help mitigate damages arising from crop yield impacts.

<sup>142</sup> The analogous DSCIM results for 2030 emissions of CH<sub>4</sub> and N<sub>2</sub>O (under a near-term Ramsey discount rate of 2%) are \$75/mtCH<sub>4</sub> and \$3,800/mtN<sub>2</sub>O, rising to \$382/mtCH<sub>4</sub> and \$8,500/mtN<sub>2</sub>O by 2080.

<sup>143</sup> The analogous GIVE results for 2030 emissions of CH<sub>4</sub> and N<sub>2</sub>O (under a near-term Ramsey discount rate of 2%) are \$276/mtCH<sub>4</sub> and \$5,000/mtN<sub>2</sub>O, rising to \$534/mtCH<sub>4</sub> and \$7,900/mtN<sub>2</sub>O by 2080.

cultural, and humanitarian connections around the world; the U.S. government has personnel, military assets, and investments around the world. Also, climate change is likely to worsen—for example—public health, change migration patterns, and disrupt aspects of global supply chains. Changing economic and health conditions across countries will impact U.S. business, investments, and travel abroad. In addition to the economic consequences, unrest and political instability in foreign countries are expected to have national security ramifications for the U.S. (DoD 2021). Empirical estimates of some international spillover impacts have started to appear in the academic literature. For example, as noted in IPCC (2022), “Schenker (2013) estimated that the climate impacts on trade from developing to developed countries could be responsible for 16.4% of the total expected cost of climate change in the US in 2100.” Third, the estimates do not address the implications of how changes in U.S. GHG emissions may induce GHG mitigation actions by other countries. As discussed in Section 1, this is another consideration affecting the climate benefits to U.S. citizens and residents resulting from a domestic policy that reduces U.S. GHG emissions. For these reasons, as discussed in Section 1, such estimates of damages from climate change impacts physically occurring within the U.S. do not provide a robust estimate of damages to U.S. citizens and residents.

The GIVE and DSCIM estimates of damages physically occurring within the U.S. are also subject to the broader set of limitations discussed in Section 3.2, including the omission of important damage categories that may be especially relevant to assessing the climate damages experienced by U.S. citizens and residents, such as the omission of wildfire damages.

**Additional modeling efforts.** Additional modeling efforts can shed further light on some omitted damage categories. For example, the Framework for Evaluating Damages and Impacts (FrEDI) is an open-source modeling framework developed by the EPA<sup>144</sup> to characterize net annual climate change impacts in individual impact categories within the contiguous U.S. and monetize the associated distribution of modeled damages (EPA 2021d, Sarofim et al. 2021b). FrEDI includes more than 20 specific impact categories, many with multiple adaptation scenarios and sub-impacts, with the capability to disaggregate results across seven U.S. geographic regions.<sup>145</sup> The FrEDI framework was originally developed to calculate annual impacts through the year 2100, associated with custom projections of future temperature (or

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<sup>144</sup> The FrEDI framework and Technical Documentation (EPA 2021d) have been subject to a public review comment period and an independent external peer review, following guidance in the EPA Peer-Review Handbook for Influential Scientific Information (ISI). Information on the FrEDI peer-review is available at the EPA Science Inventory: [https://cfpub.epa.gov/si/si\\_public\\_record\\_report.cfm?dirEntryId=351316&Lab=OAP&simplesearch=0&showcriteria=2&sortBy=pubDate&timstype=&searchall=FrEDI](https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=351316&Lab=OAP&simplesearch=0&showcriteria=2&sortBy=pubDate&timstype=&searchall=FrEDI).

<sup>145</sup> FrEDI uses estimates of physical and economic impacts of climate change by degree of warming, developed from peer-reviewed sectoral impact studies, to project annual climate-driven impacts resulting from any warming scenario. FrEDI is designed to synthesize the results of a broad range of peer-reviewed climate change impact and damage projections into a common analytical framework, including those derived from econometric approaches and detailed, process-based simulation models. These currently include various impacts to human health, coastal and inland property (e.g., from SLR, flooding and storms), transportation and other infrastructure, energy demand and supply, water resources, labor, and winter recreation. Currently, all impacts in FrEDI are based on changes in temperature or SLR, although the relationship between climate and impacts in the underlying models often includes other factors, such as precipitation. FrEDI employs a variety of assumptions regarding adaptive responses to climate impacts. EPA (2021d) provides a complete list of endpoints and details regarding the scope and assumptions for each sector. FrEDI also has some ability to disaggregate results across various demographic groups living within U.S. borders. For additional description of FrEDI please see [www.epa.gov/cira/fredi](http://www.epa.gov/cira/fredi) and [www.github.com/USEPA/FrEDI](https://www.github.com/USEPA/FrEDI).

emissions) and socioeconomic scenarios (GDP and population). Estimates of net annual impacts<sup>146</sup> from climate change are often presented in the IPCC and USGCRP assessments. While related, estimates of the net annual impacts of climate change are different than the future stream of net damages associated with adding one ton of a GHG to the atmosphere in a given year (i.e., the SC-GHG).

Results from FrEDI<sup>147</sup> show that annual damages resulting from climate change impacts within the contiguous U.S. (CONUS) (i.e., excluding Hawaii, Alaska and U.S. territories) and for impact categories not represented in GIVE and DSCIM are expected to be substantial. For example, under the RFF-SPs and FaIR model temperature outputs used within this report, FrEDI estimates net total undiscounted annual climate-driven damages across the 20 modeled impact categories in the CONUS to be \$380 billion (2020 dollars) (95% CI: \$280-660 billion) in 2030, increasing to \$2.9 trillion (95% CI: \$510 billion to \$12 trillion) in 2090 (Hartin et al. 2023).<sup>148, 149</sup> Some of the impacts not appearing in DSCIM or GIVE but having large economic damages estimated in FrEDI include: transportation related damages from hightide flooding (\$140 billion in 2090), premature mortality from climate-driven changes in ozone and PM<sub>2.5</sub> (\$240 billion in 2090), wildfire emission health impacts and suppression response costs (\$51 billion annually in 2090), and property damage from hurricane winds (\$28 billion in 2090) (Hartin et al. 2023). As described in Hartin et al. (2023), FrEDI has also been extended to 2300 to calculate the net present value of damages in the CONUS region from a marginal pulse of CO<sub>2</sub>, CH<sub>4</sub>, or N<sub>2</sub>O emissions. Using the RFF-SPs, FaIR model temperature outputs, and the 2% near-term Ramsey discounting approach employed elsewhere within this report, FrEDI estimates a partial SC-CO<sub>2</sub> of \$37 per mtCO<sub>2</sub> for damages physically occurring within CONUS for 2030 emissions.<sup>150</sup>

While the FrEDI results help to illustrate how monetized damages physically occurring within CONUS increase as more impacts are reflected in the modeling framework, they are still subject to many of the

<sup>146</sup> Net damages for a given year are based on the temperature and sea level change between the FrEDI baseline (1986-2005 average) and the presented year. Those temperature and sea level changes in that last year are the result of the emission driven changes in concentrations and radiative forcing over that entire timespan (2005-2090).

<sup>147</sup> [https://github.com/USEPA/FrEDI/releases/tag/FrEDI\\_2300](https://github.com/USEPA/FrEDI/releases/tag/FrEDI_2300)

<sup>148</sup> Inputs to FrEDI include a time series of global mean temperature change relative to the 1986-2005 average (FrEDI baseline), calculated from an ensemble of 10,000 FaIR v1.6.2 runs associated with RFF-SP projected emissions, as well as time series of U.S. GDP (in 2015\$) and U.S. population from the RFF-SPs. Populations in each of the 7 National Climate Assessment regions (i.e., Northeast, Southeast, Midwest, Northern Great Plains, Southern Great Plains, Southwest, Northwest) were calculated from the RFF-SP national total populations (including AK, HI, & territories) multiplied by the regional percentage of total CONUS population, derived from ICLUS (EPA 2017). Under this approach, RFF-SP population counts for AK, HI, and U.S. territories (< 2% of national population) are distributed to each CONUS regions following the ICLUS-derived ratios. FrEDI provides annual damage estimates in 2015USD, brought to 2020USD for this report using U.S. Bureau of Economic Analysis Table 1.1.9 (BEA 2023b) (specifically, using 2020USD = 2015USD x (113.648 / 104.691)).

<sup>149</sup> Since the 2022 Draft Report, the FrEDI analysis updated both the underlying study and income elasticity used to project temperature mortality impacts to be more consistent with the GIVE model. Both updates resulted in changes to the FrEDI-projected health category impacts and both have been peer-reviewed in Hartin et al., (2023).

<sup>150</sup> Hartin et al. (2023) present partial SC-CO<sub>2</sub>, SC-CH<sub>4</sub>, and SC-N<sub>2</sub>O estimates for a 2020 emissions pulse year. This same methodology is applied in this report to calculate the FrEDI-based partial SC-GHG values for 2030 emissions. The analogous FrEDI results for 2030 emissions of CH<sub>4</sub> and N<sub>2</sub>O (under a near-term Ramsey discount rate of 2%) are \$594/mtCH<sub>4</sub> and \$11,010/mtN<sub>2</sub>O. FrEDI estimates in this report are additionally corrected using Equation A.3.9 to account for certainty-equivalency in the discount rate (< 5% adjustment).

same limitations associated with the DSCIM and GIVE damage modules discussed in Section 3.2, including the omission or partial modeling of important damage categories. For example, the FrEDI estimates do reflect some important health damages from U.S. wildfires (i.e., mortality and morbidity impacts from wildfire smoke) and suppression costs, but do not yet account for other market and non-market welfare effects of wildfires (e.g., property damage, impacts to ecosystem services, climate feedback effects from wildfire CO<sub>2</sub> emissions, etc.). Similarly, FrEDI estimates expand on the types of modeled damages from SLR (e.g., traffic delays due to flooded coastal roadways) but do not reflect others, such as the effect of groundwater intrusion, business interruptions, debris removal costs, or critical infrastructure loss. In addition, while FrEDI includes a larger set of CONUS climate-driven impacts, many of the impacts listed in Table 3.2.1 that are omitted from DSCIM and GIVE are also not yet reflected in FrEDI, such as climate-mediated effects to ecosystem services, national security, or extreme weather events. Likewise, none of the SC-GHG estimates currently reflect damages to U.S. extraterritorial interests or spillover effects from climate impacts occurring on foreign soil. As described in the recent Fifth National Climate Assessment (USGCRP 2023), “Climate change impacts beyond U.S. borders expose U.S. economic, trade, and investment interests to risk because they are highly integrated in the global economy” (Hellmuth et al. 2023). These international effects include, for example, direct effects on U.S. citizens and assets located abroad, U.S. business investments overseas, foreign agricultural production shocks affecting U.S. markets, exports, and farm income (Hellmuth et al. 2023), and smoke pollutants emitted by wildfires outside U.S. borders (e.g., Canada) negatively impacting human health, visibility, and solar energy generation (West et al. 2023). U.S. interests will also be affected through spillover pathways such as economic and political destabilization and global migration that can lead to adverse impacts on U.S. national security, public health, and humanitarian conditions (Hellmuth et al. 2023).

Another method that has produced estimates of the effect of climate change on U.S.-specific outcomes uses a top-down approach to estimate aggregate damage functions. These studies include total-economy empirical studies that econometrically estimate the relationship between GDP and a climate variable, usually temperature. Studies in this strand of the literature that estimate U.S.-specific response functions include, for example, Burke et al. (2015), Acevedo et al. (2020), Kalkuhl and Wenz (2020), and Kahn et al. (2021). Using the damage function relationship estimates by Burke et al. (2015), Ricke et al. (2018) report a U.S.-specific SC-CO<sub>2</sub> of \$48/mtCO<sub>2</sub>, under a SSP2-RCP6.0 socioeconomic-warming scenario and Ramsey discounting with  $\rho = 2$  and  $\eta = 1.5$ . The median estimate from Ricke et al.’s (2018) analysis ranges from \$9-\$332/mtCO<sub>2</sub> depending on the damage function specification, socioeconomic scenario, and discount rate. However, the modeling framework and summary statistics of Ricke et al. (2018) differs in important ways from the approach used in this report to estimate the SC-GHG (e.g., discounting, risk aversion, and scenario uncertainty). Updating the framework of Ricke et al. (2018) to be consistent with the methods described in Section 2, or considering other total-economy empirical damage functions, would require new analysis. Finally, because these total-economy empirical studies estimate market impacts, they do not include non-market impacts of climate change (e.g., mortality impacts) and therefore are only a partial estimate.

Finally, as with DSCIM and GIVE, the U.S. focused modeling efforts discussed above do not reflect non-climate mediated effects of GHG emissions experienced by U.S. populations (other than CO<sub>2</sub> fertilization effects on agriculture). However, recent research investigating these other effects of GHGs find damages to be substantial. As discussed in Section 3.2 above, one example of new research on non-climate

mediated effects of methane emissions comes from McDuffie et al. (2023) who estimate the monetized increase in respiratory-related human mortality risk from the ozone produced from a marginal pulse of methane emissions. Using the socioeconomics from the RFF-SPs and the 2% near-term Ramsey discounting approach employed elsewhere within this report, the net present value of the additional risk to U.S. populations is on the order of \$320 per  $\text{mtCH}_4$  for a pulse of methane emissions in 2030.<sup>151</sup>

Taken together, the numerous explicitly omitted damage categories and other modeling limitations discussed above and throughout Section 2 make it likely that the DSCIM and GIVE damage modules, and FrEDI, significantly underestimate the benefits of GHG mitigation to U.S. citizens and residents. The EPA will continue to review advances in the literature, including robust methodologies for estimating the magnitude of the various direct and indirect damages to U.S. populations from climate impacts occurring abroad and reciprocal international mitigation activities.

Just as there is heterogeneity in the distribution of climate change damages across the globe, the scope and magnitude of climate change impacts is not uniform across the U.S. Although subnational detail on the distribution of impacts and associated monetized damages is not available from the SC-GHG modeling presented in Section 3.1,<sup>152</sup> scientific assessment reports and additional modeling efforts can shed further light on the distribution of damages expected to occur within the U.S. For example, scientific assessment reports on climate change produced over the past decade by the U.S. Global Change Research Program provide detailed findings as to the distribution of climate changes impacts across the U.S. (e.g., USGCRP 2016, 2018a, 2023). Modeling efforts using a predecessor of DSCIM (e.g., Hsiang et al. 2017) and using the FrEDI model provide additional information about how damages are expected to be substantial and distributed unevenly across U.S. regions. For example, of the impact categories examined in FrEDI (Hartin et al. 2023), the largest source of modeled damages differed from region to region, with wildfire impacts in the Northwest, air quality impacts on the East Coast and the Southwest, labor productivity impacts in the Midwest, transportation impacts from high tide flooding in the Southern Plains, and damages to rail infrastructure in the Northern Plains. In addition, a growing body of literature is focusing on the disproportionate and unequal risks that climate change is projected to have on communities that are least able to anticipate, cope with, and recover from adverse impacts. National Academies of Science, Engineering, and Medicine reports provide evidence of how the impacts of climate change create potential environmental justice concerns (NRC 2011, National Academies 2017). For a recent detailed discussion of climate change impacts in the U.S. and their intersection with environmental justice concerns, see the 2021 Climate Change and Social Vulnerability report (EPA 2021e).

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<sup>151</sup> McDuffie et al. (2023) report global and country-specific net present damages associated with increases in respiratory-related human mortality attributable to exposure to tropospheric ozone that was produced from a marginal pulse of methane emissions in the year 2020 (U.S.: \$270/ $\text{mtCH}_4$ ). Methods described in McDuffie et al. (2023) use the same RFF-SP data, monetization, and discounting approaches as described in this report. In this report, the methodology described in McDuffie et al., (2023) is replicated to additionally calculate the net present value of damages in the U.S. from methane produced ozone associated with a pulse of  $\text{CH}_4$  emissions in 2030.

<sup>152</sup> The GIVE damage module is only resolved at the country level, such that subnational detail on the distribution of impacts is not available. The DSCIM damage module is resolved at a spatial resolution resembling counties, though that level of detail is unavailable for the model results based on the probabilistic socioeconomic scenarios used in this report.

## 4 Using SC-GHG Estimates in Policy Analysis

This section discusses how the SC-GHG results presented in Section 3.1 can be used in the EPA analysis of policies that affect GHG emissions. Section 4.1 presents a combination of the multiple lines of evidence on damages into a manageable number of values for policy analysis. Section 4.2 describes how the SC-GHG values are applied to a stream of estimated emissions changes in an analysis.

### 4.1 Combining Lines of Evidence on Damages

The SC-GHG estimation process in this report produces nine separate estimates of the SC-CO<sub>2</sub>, SC-CH<sub>4</sub>, and SC-N<sub>2</sub>O for a given year, the product of three damage modules and three discount rates. To produce a range of estimates that reflects the uncertainty in the estimation exercise while providing a manageable number of estimates to incorporate into policy analysis, the multiple lines of evidence on damage modules can be combined by averaging the results presented in Table 3.1.1, Table 3.1.2, and Table 3.1.3 across the three damage module specifications. In assigning equal weight to each damage module specification no underlying line of evidence is given greater weight than another. As discussed in Section 2.3, the damage modules in GIVE and DSCIM are based on different underlying information, data sources, and estimation methods.<sup>153</sup> GIVE and DSCIM are both independent lines of evidence from the meta-analysis-based damage module since the studies underlying each damage category in GIVE and DSCIM are not included in Howard and Sterner's (2017) final sample of studies.

Table 4.1.1 presents the resulting SC-GHG estimates for each emissions year, gas, and near-term target discount rate after averaging across three damage module specifications. This table displays the rounded values; the annual unrounded values for use in calculations are available for all emissions years over 2020-2080 in Table A.5.1 in the Appendix.

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<sup>153</sup> Only one component of the methodology for calculating coastal damages is common across the two models. Both DSCIM and GIVE rely on the CIAM model developed by Diaz (2016) to estimate the economic damages resulting from projections of SLR. This small degree of overlap across the two modules is unlikely to affect the representation of structural uncertainty when pooling estimates across the two damage modules.



*Table 4.1.1: Estimates of the Social Cost of Greenhouse Gases (SC-GHG), 2020-2080 (in 2020 dollars per metric ton)*

| Emission<br>Year | SC-GHG and Near-term Ramsey Discount Rate                               |      |      |                                                                         |       |       |                                                                          |         |         |
|------------------|-------------------------------------------------------------------------|------|------|-------------------------------------------------------------------------|-------|-------|--------------------------------------------------------------------------|---------|---------|
|                  | SC-CO <sub>2</sub><br>(2020 dollars per metric ton of CO <sub>2</sub> ) |      |      | SC-CH <sub>4</sub><br>(2020 dollars per metric ton of CH <sub>4</sub> ) |       |       | SC-N <sub>2</sub> O<br>(2020 dollars per metric ton of N <sub>2</sub> O) |         |         |
|                  | 2.5%                                                                    | 2.0% | 1.5% | 2.5%                                                                    | 2.0%  | 1.5%  | 2.5%                                                                     | 2.0%    | 1.5%    |
| 2020             | 120                                                                     | 190  | 340  | 1,300                                                                   | 1,600 | 2,300 | 35,000                                                                   | 54,000  | 87,000  |
| 2030             | 140                                                                     | 230  | 380  | 1,900                                                                   | 2,400 | 3,200 | 45,000                                                                   | 66,000  | 100,000 |
| 2040             | 170                                                                     | 270  | 430  | 2,700                                                                   | 3,300 | 4,200 | 55,000                                                                   | 79,000  | 120,000 |
| 2050             | 200                                                                     | 310  | 480  | 3,500                                                                   | 4,200 | 5,300 | 66,000                                                                   | 93,000  | 140,000 |
| 2060             | 230                                                                     | 350  | 530  | 4,300                                                                   | 5,100 | 6,300 | 76,000                                                                   | 110,000 | 150,000 |
| 2070             | 260                                                                     | 380  | 570  | 5,000                                                                   | 5,900 | 7,200 | 85,000                                                                   | 120,000 | 170,000 |
| 2080             | 280                                                                     | 410  | 600  | 5,800                                                                   | 6,800 | 8,200 | 95,000                                                                   | 130,000 | 180,000 |

Note, given the relatively modest variation in the SC-GHG estimates across the three damage modules in Tables 3.1.1-3.1.3, the values presented in Table 4.1.1 are similar to what would be obtained under alternative approaches for drawing on the multiple lines of evidence represented by the three damage modules. For example, if the estimates for each model were weighted in such in way that the weighted average is the certainty-equivalent across the models,<sup>154</sup> the average (unrounded) SC-CO<sub>2</sub> in emissions year 2020 would change by less than 1% for all three near-term discount rates. The SC-GHG estimates resulting from averaging across the models (as presented in Table 4.1.1) are also similar to the central estimates presented in Tables 3.1.1-3.1.3. That is, the unrounded estimates based on the DSCIM damage module for the 2.5% discount rate, and the GIVE damage module for the 2% and 1.5% discount rates, in emissions year 2020 differ from the three-model average estimates by only 2% (2.5% discount rate), -1% (2% discount rate), and -1% (1.5% discount rate).

The SC-GHG estimates presented in Table 4.1.1 are larger in magnitude than the IWG recommended interim SC-GHG estimates published in the February 2021 TSD. For CO<sub>2</sub>, the central SC-CO<sub>2</sub> estimate (based on a 2% near-term Ramsey discount rate) of \$190/mtCO<sub>2</sub> for 2020 emissions is around 280% larger than the IWG recommended interim estimate based on the 3% constant discount rate (\$51/mtCO<sub>2</sub>). For SC-CH<sub>4</sub>, the central estimate (based on a 2% near-term Ramsey discount rate) of \$1,600/mtCH<sub>4</sub> for 2020 emissions is around 10% greater than the IWG recommended interim estimate based on the 3% constant discount rate (\$1,500/mtCO<sub>2</sub>). For SC-N<sub>2</sub>O, the central estimate (based on a 2% near-term Ramsey

<sup>154</sup> Specifically, the weight is estimated for each module, near-term discount rate and emission year using:  $w_{\tau,m,\eta} = \frac{E[(C_{\tau,m})^{-\eta}]}{\sum_m^M E[(C_{\tau,m})^{-\eta}]}$ , where  $c$  is consumption net climate change,  $\tau$  is emission year,  $m$  is damage module, and  $\eta$  is the elasticity of marginal utility with respect to consumption. The resulting weights given to the damage module based on DSCIM, GIVE, and Howard and Sterner (2017) are: 0.331, 0.334, 0.334, respectively, under Ramsey discounting with a 2.0% near-term target rate. These weights are close to an equal weight (0.333) on modules. These three modules share the same distributions of GDP and have estimates of damage under climate change that are comparable. Therefore, the distributions of net consumption across the three modules are similar, leading to similar weights.

discount rate) of \$54,000/mtN<sub>2</sub>O for 2020 emissions is around 190% greater than the IWG recommended interim estimate based on the 3% constant discount rate (\$18,000/mtN<sub>2</sub>O).

The increases in the SC-GHG estimates are due to the combined effect of the methodological updates described in Section 2 of this report, some of which are integrated in a way that makes a complete decomposition of the incremental contribution of each change difficult for all three damage functions used in the damage module. For example, a comparison of SC-GHG estimates based on a constant 3% discount rate with results based on a 2% near-term Ramsey discount rate reflects the combined effect of both (1) using a lower near-term rate and (2) the shift from a constant to a dynamic discounting approach that accounts for correlation between climate change damages and consumption growth through the use of probabilistic RFF-SPs growth projections. A re-estimation of the IWG recommended interim estimates using lower constant discount rates finds that the SC-CO<sub>2</sub> increases from \$51/mtCO<sub>2</sub> to \$121/mtCO<sub>2</sub> for 2020 emissions when shifting from a constant 3% to a constant 2% discount rate (NYSDEC 2022). This illustrates that the combined effect of shifting to a dynamic discount rate approach together with the socioeconomic, climate, and damage module updates accounts for the additional 60% increase in the SC-CO<sub>2</sub> to \$190/mtCO<sub>2</sub> for 2020 emissions presented in Table 4.1.1. This does not imply that each update influences the SC-GHG in the same direction. For example, ignoring the correlation between climate change damages and consumption growth – as is the case with a constant discount rate approach – can lead to overestimating the SC-GHG if there is a positive correlation between consumption growth and marginal damages.<sup>155</sup> In the case of methane, the IWG interim SC-CH<sub>4</sub> estimate under a 2% constant discount rate (\$2,700/mtCH<sub>4</sub> for 2020 emissions (NYSDEC 2022)) exceeds the fully updated SC-CH<sub>4</sub> estimate under a 2% near-term Ramsey discount rate presented in Table 4.1.1.<sup>156</sup>

The finding of an increase in SC-CO<sub>2</sub> estimates relative to IWG estimates to date is consistent with recent research. Estimates of the SC-CO<sub>2</sub> in the academic literature have increased over time as the available methods and data have improved. In a meta-analysis of estimates of the SC-CO<sub>2</sub>, Tol (2023) finds that as knowledge of the effects of climate change expands, the estimates of the SC-CO<sub>2</sub> in the past 10 years have increased more than fourfold after controlling for inflation, emissions year, and discount rate used. Tol's finding of a statistically significant time trend in SC-CO<sub>2</sub> estimates provides support for the increasing trend noted in other recent studies (e.g., Hänsel et al. 2020, Wagner 2021, van den Bergh and Botzen 2014, Wang et al. 2019).

The near-term SC-CO<sub>2</sub> estimates reported in Table 4.1.1 are also comparable in magnitude to recent published SC-CO<sub>2</sub> estimates that were developed using non-IAM based approaches. For example, Pindyck's (2019) recent survey of several hundred experts in climate science and climate economics

<sup>155</sup> See, for example, Newell et al. (2022) and Rennert et al. (2022b) for an illustration of this potential. Table 1 in Rennert et al. (2022b) also provides an analysis that illustrates the incremental impact of some of the other updates in the GIVE model, relative to a recent version of the DICE model. For example, the authors find that the use of the GIVE damage functions increases the SC-CO<sub>2</sub> by 36% (from \$59/tCO<sub>2</sub> to \$80/tCO<sub>2</sub> for 2020 emissions), relative to a model run that uses the updated Fair-based climate modelling, the RFF-SP socioeconomic module, and the Ramsey discounting approach reflecting a 3% near-term discount rate but retains the DICE 2016R damage function.

<sup>156</sup> For a full listing of the IWG SC-GHG recommended values re-estimated using lower constant discount rates, see NYSDEC (2022), available at: <https://www.dec.ny.gov/regulations/56552.html>.

yielded mean SC-CO<sub>2</sub> estimates on the order of \$200 per metric ton CO<sub>2</sub>.<sup>157</sup> Studies using other types of survey techniques have found similar ranges of SC-CO<sub>2</sub> estimates. For example, based on the results of a vehicle choice experiment, Hulshof and Mulder (2020) derived a mean willingness-to-pay estimate for CO<sub>2</sub> emission reduction of \$236 per metric ton CO<sub>2</sub>.<sup>158</sup> An earlier vehicle choice survey by Achtnicht (2012), using a different population and a somewhat different method to translate the WTP for clean cars into WTP for emission reductions, found car buyers to be willing to pay between \$130 and \$372 per metric ton of CO<sub>2</sub> reduced.<sup>159</sup>

## 4.2 Application of SC-GHG Estimates in Benefit-Cost Analysis

The SC-GHG reflects the future stream of damages associated with an additional ton of emissions discounted back to the year of the emissions. Several steps are necessary when using the SC-GHG estimates in an analysis that includes GHG emissions changes in multiple future years in addition to other benefits and costs. First, the gas-specific SC-GHG estimates corresponding to the year of estimated emissions change need to be applied and discounted to the year of analysis to monetize the emissions. Second, the monetized GHG emissions impacts need to be incorporated with other costs and benefits considered in the analysis.

The SC-GHG estimates presented in Table 4.1.1 represents the damages associated with each additional ton of emissions released discounted back to the year of emissions. To calculate the monetized value of damages from emissions in year  $\tau$  discounted back to the year of analysis, denoted as year 0, two steps are required. First, the emissions changes in the future year,  $x_\tau$ , are multiplied times the SC-GHG in that future year,  $scghg_\tau$ , to obtain the future monetized net damages associated with those emissions. Second, that value needs to be discounted back to the year of analysis to obtain the present value of the damages,  $pv_0$ , using the discount factor  $\tilde{\delta}_\tau$ . Mathematically, these two steps can be written as

$$pv_0 = x_\tau \cdot scghg_\tau \cdot \tilde{\delta}_\tau. \quad (4.2.1)$$

The correct discount factor to use when discounting the SC-GHG estimates presented in this report is the certainty-equivalent discount factor,  $\tilde{\delta}_\tau$ . This is because the SC-GHG estimates are certainty-equivalent values that account for the uncertainty in future consumption per capita. As described more fully in Appendix A.3, the certainty-equivalent discount factor incorporates the uncertainty in future consumption using the RFF-SP probabilistic growth scenarios. Discounting the SC-GHG estimates using a constant discount rate equal to the near-term target rate would not capture the uncertainty in

<sup>157</sup> Pindyck's (2019) full sample of respondents yielded mean SC-CO<sub>2</sub> estimates above \$200/mtCO<sub>2</sub>, after dropping responses where values fell outside the 5<sup>th</sup> or 95<sup>th</sup> percentiles. Responses from economists were lower (on average \$174) while the mean SC-CO<sub>2</sub> for other groups was close to \$300. To further illustrate the heterogeneity in responses, Pindyck (2019) also reported results based on further trimming of responses, e.g., to 10<sup>th</sup> through 90<sup>th</sup> percentile values (which reduces mean SC-CO<sub>2</sub> estimates to \$147-243/mtCO<sub>2</sub>), or to the experts who reported high confidence in their impact probabilities (which reduced mean SC-CO<sub>2</sub> estimates to \$108-138/mtCO<sub>2</sub>).

<sup>158</sup> We convert the results reported in Hulshof and Mulder (2020) to U.S. dollars using December 2017 exchange rates (1.1836 USD/Euro (<https://www.federalreserve.gov/datadownload/Choose.aspx?rel=H10>)), the month the survey was administered.

<sup>159</sup> We convert the results reported in Achtnicht (2012) to U.S. dollars using the average exchange rate during the time period when the survey was administered, August 2007 through March 2008 (1.4502 USD/Euro (<https://www.federalreserve.gov/datadownload/Choose.aspx?rel=H10>)).

consumption per capita for that year. This means that precise discounting of a stream of future emissions requires the SC-GHG for each year (provided in Table A.5.1) together with the certainty-equivalent discount factor for that year.

While applying the certainty-equivalent discount factor would ensure a full accounting of scenario uncertainty, this process introduces substantial complexity in the calculations, which may not be warranted in all situations. If the stream of future emissions being evaluated is moderate (e.g., 30 years or less), the difference between discounting from the year of emissions to the year of analysis using a constant discount rate equal to the near-term target rate, and discounting using the certainty-equivalent discount factor,  $\tilde{\delta}_\tau$  will be small. For example, if the year of analysis is 2024 using the near-term target rate to discount back from the year of emissions instead of the certainty-equivalent discount factor will underestimate the present value emission reductions by less than 1% for the first ten years of future emissions. The present value of emission reductions 30 years in the future will be underestimated by about 2% relative to the more complete calculation.<sup>160</sup> The differences from using a constant discount rate rather than the certainty-equivalent discount factor for each year in the future are provided in Figure A.3.1. Therefore, discounting the monetized value of emission reductions over the first 30 years of the analysis using the near-term target rate provides a close approximation.

## 5 Summary

This report presents new estimates of the SC-GHG that reflect recent advances in the scientific literature on climate change and its economic impacts and recommendations made by the National Academies of Science, Engineering, and Medicine in 2017.

Since 2008, the EPA has used estimates of the SC-GHG in analyses of actions that affect GHG emissions. The values used by the EPA from 2009 to 2016, and since 2021, have been consistent with those developed and recommended by the Interagency Working Group on the SC-GHG (IWG), and the values used from 2017-2020 were consistent with those required by E.O. 13783. During that time, the National Academies conducted a comprehensive review of the social cost of carbon and issued a final report in 2017 that recommended specific criteria for future updates to the SC-CO<sub>2</sub> estimates, a modeling framework to satisfy the specified criteria, and both near-term updates and longer-term research needs pertaining to various components of the estimation process. The IWG was reconstituted in 2021 and E.O. 13990 directed it to develop a comprehensive update of its SC-GHG estimates, recommendations regarding areas of decision-making to which SC-GHG should be applied, and a standardized review and updating process to ensure that the recommended estimates continue to be based on the best available economics and science going forward.

The EPA is a member of the IWG and is participating in the IWG's work under E.O. 13990. While that process continues, this report presents a set of SC-GHG estimates that incorporates recent research addressing the near-term recommendations of the National Academies. The report takes a modular approach in which the methodology underlying each of the four components, or modules, of the SC-GHG

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<sup>160</sup> This example is based on the SC-GHG estimates using a 2% near-term Ramsey discount rate. The quantitative results will vary slightly across the near-term target rates considered in this report, but the difference between the two approaches remains relatively small over the first 30 years.

estimation process – socioeconomics and emissions, climate, damages, and discounting – is developed by drawing on the latest research and expertise from the scientific disciplines relevant to that component. Table 5.1 summarizes the key elements of the National Academies’ near-term recommendations for each module and how the methodological updates employed in this report addressed those recommendations.

The EPA is continuing to investigate ways to address the longer-term recommendations from the National Academies pertaining to each module. For example, as discussed in Section 3.2, there are opportunities for further improvements in the representation of various categories of climate damages. For the damages module, the National Academies recommended the following:

“In the longer term, the IWG should develop a damages module that meets the overall criteria for scientific basis, transparency, and uncertainty characterization (see Recommendation 2-2, in Chapter 2) and has the following five features:

1. It should disaggregate market and non-market climate damages by region and sector, with results that are presented in both monetary and natural units and that are consistent with empirical and structural economic studies of sectoral impacts and damages.
2. It should include representation of important interactions and spillovers among regions and sectors, as well as feedbacks to other modules.
3. It should explicitly recognize and consider damages that affect welfare either directly or through changes to consumption, capital stocks (physical, human, natural), or through other channels.
4. It should include representation of adaptation to climate change and the costs of adaptation.
5. It should include representation of nongradual damages, such as those associated with critical climatic or socioeconomic thresholds.” (National Academies 2017, pp. 25-26).

Many of these recommendations were echoed by the peer reviewers of the 2022 draft of this report, especially with regard to categories of climate impacts and associated damages that are not yet represented in the SC-GHG estimates presented in this report. Finally, the National Academies outlined a set of long-term research priorities as a guide for making future improvements to SC-GHG estimation. The National Academies’ committee noted “that neither the IWG nor any other single entity has responsibility for identifying and supporting research in these fields. Thus, these conclusions on what is needed are intended for all interested researchers, institutions that support research, and policy makers.”

To conclude, the modeling implemented in this report reflects methodological choices that go in the direction of offering a partial representation of several types of climate change damages, and, given both those choices and the numerous categories of damages that are not currently quantified at all and other model limitations, the resulting SC-GHG estimates likely underestimate the marginal damages from greenhouse gas pollution. The EPA will continue to review developments in the literature, including more robust methodologies for estimating the magnitude of the various direct and indirect damages from GHG emissions, and look for opportunities to further improve SC-GHG estimation going forward.

*Table 5.1: Implementation of National Academies Recommendations in this Report*

| Near-term National Academies' recommendations                                                                                                                                                                         | Methodological updates employed in this report                                                                                                                                                                                                                                                                                                                   |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Overarching</i>                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                  |
| □ Framework: Adopt a modular approach to allow relevant disciplinary expertise to shape each part of the analysis.                                                                                                    | □ Adopted a modular modeling framework that unbundled the socioeconomic-emissions scenarios, climate modeling, damage function modeling, and discounting to allow each component to be informed by high-quality science from the relevant disciplines.                                                                                                           |
| □ Scientific basis: Modules should be consistent with scientific knowledge in the current, peer-reviewed literature.                                                                                                  | □ Selected modeling frameworks and parameters for each module based on recent peer-reviewed scientific literature and scientific consensus reports.                                                                                                                                                                                                              |
| □ Uncertainty characterization: Key uncertainties, including functional forms, parameter assumptions, and data inputs, should be adequately represented and uncertainties not quantified should be identified.        | □ Expanded upon past estimates used by the EPA by incorporating a quantitative consideration of uncertainty into all modules and using a Monte Carlo approach to develop SC-GHG distributions that captures interactions across modules' uncertainties.                                                                                                          |
| □ Transparency: Documentation should allow readers to understand and assess the modules, including which features are evidence-based or judgment-based. Model code should be available to researchers.                | □ Documented modeling features in detail, including within replication instructions and computer code that has been made publicly available.                                                                                                                                                                                                                     |
| <i>Socioeconomic module</i>                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                  |
| □ Use statistical methods and expert elicitation for projecting probability distributions of GDP, population growth and emissions into the future.                                                                    | □ Adopted the probabilistic RFF-SPs, which provide multi-century projections of population, GDP per capita, and GHG emissions based on statistical and structured expert judgment methods that account for future policies and connections between variables.                                                                                                    |
| <i>Climate module</i>                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                  |
| □ Employ a reduced complexity Earth system model that satisfies well-defined diagnostic tests, such as the FaIR model, to represent temperature change over time, and include sea-level rise and ocean pH components. | □ Adopted FaIR 1.6.2 to serve as the basis for an updated climate module, which provides an accurate representation of the latest scientific consensus on the relationship between global emissions and global mean surface temperature under a wide range of socioeconomic emissions scenarios, complemented by the BRICK and FACTS models of sea level rise.   |
| <i>Damages module</i>                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                  |
| □ Improve and update existing damage functions to reflect recent scientific literature.                                                                                                                               | □ Adopted a suite of three updated damage functions (GIVE, DSCIM, and a meta-analysis), which together represent the major scientific lines of evidence on the economic impacts of climate change that are available, capture uncertainty, and, in the cases of GIVE and DSCIM, provide transparent bottom-up modeling that map Earth system changes to damages. |
| <i>Discounting module</i>                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                  |
| □ Incorporate the relationship between discount rates and economic growth using a Ramsey-like framework and parameters chosen consistent with theory and empirical evidence on consumption interest rates.            | □ Adopted a Ramsey discounting approach that endogenously connects the discount rate and the socioeconomic scenarios and where the parameters are empirically calibrated based on observed behavior of interest rates and economic growth.                                                                                                                       |

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## A. Appendix

### A.1. Additional Discussion of Scientific Updates in IPCC's Sixth Assessment Report

Several updates to the science of greenhouse gas radiative efficiency<sup>161</sup>, atmospheric lifetimes, and chemistry have been made since the IWG published its first set of recommended SC-GHG estimates in 2010. In this report projections of temperature change from a pulse of GHG emissions are based on the FaIR climate model, version 1.6.2, rather than using the simplified lifetime and forcing equations from the IPCC AR4 assessment that were embedded in the IAMs underlying the SC-GHG estimates used to date. While FaIR is a more complex model that includes internal feedbacks and chemistry such that gas lifetimes and interactions are not constant, it can be instructive to examine how the more simplistic equations have been updated between AR4 (IPCC 2007b) and AR6 (IPCC 2021b) as FaIR 1.6.2 reflects many of the same scientific advances in understanding.

The radiative efficiency of all gases has been updated, in part because of updates to the science and in part because radiative efficiency is a function of background concentrations. The radiative efficiency of CO<sub>2</sub> has decreased by 5% relative to AR4, while the radiative efficiencies of CH<sub>4</sub> and N<sub>2</sub>O have both increased by about 5%. AR6 also updated the indirect effects of CH<sub>4</sub> and N<sub>2</sub>O that occur through atmospheric chemistry. The indirect radiative effects of CH<sub>4</sub> that occur through increases in ozone and stratospheric water vapor decreased by about 6%. Meanwhile, the radiative effects of N<sub>2</sub>O now include the impact of N<sub>2</sub>O on CH<sub>4</sub> and stratospheric ozone, leading to a decrease in N<sub>2</sub>O radiative efficiency of almost 13%. When accounting for all radiative changes, the effective radiative efficiency of CH<sub>4</sub> has increased by about 10%, while that of N<sub>2</sub>O has decreased by almost 8%, relative to AR4.

Separately, the AR6 estimate of lifetime of CH<sub>4</sub> decreased by about 2%, and that of N<sub>2</sub>O by about 4%, relative to AR4. The changes in the CO<sub>2</sub> lifetime are more complex, but over 100 years, the effective lifetime of CO<sub>2</sub> increased by about 13%. AR6 also included the possibility of accounting for the CO<sub>2</sub> produced through the oxidation of CH<sub>4</sub> of fossil origins in the atmosphere, using an oxidation factor of 0.75 to account for CH<sub>4</sub> that does not oxidize to CO<sub>2</sub> but rather leaves the atmosphere through a deposition process.<sup>162,163</sup> AR6 also accounts for the climate-carbon feedbacks that result from non-CO<sub>2</sub> greenhouse gases warming the atmosphere and impacting the carbon cycle; in AR4, this effect was only included for CO<sub>2</sub>.

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<sup>161</sup> Radiative efficiency is a measure of a gas' greenhouse gas strength, defined as the change in radiative forcing for a unit change in the atmospheric concentration of a gas (in W/m<sup>2</sup>/ppb).

<sup>162</sup> While FaIR 1.6.2 reflects the advances in understanding presented in AR6, FaIR 1.6.2 uses a constant CH<sub>4</sub> lifetime of 9.3 years, which is shorter than the IPCC perturbation lifetime. This assumption was documented in Smith et al. (2018) as being necessary to reproduce historical natural emissions and projected concentration scenarios. While FaIR 1.6.2 has the capability to include the oxidation of fossil CH<sub>4</sub> to CO<sub>2</sub>, the default (and the version used for the AR6 calibration) did not use this capability.

<sup>163</sup> Note that inventories based on using GWPs often use the non-fossil value for all CH<sub>4</sub> emissions because in some cases there is a potential for CO<sub>2</sub> double counting: for example, if complete combustion is assumed when calculating CO<sub>2</sub> emissions from a natural gas turbine, then the carbon from any methane leakage has already been accounted for.

Including all these scientific updates to lifetimes, atmospheric chemistry interactions, and radiative efficiency, the AR6 assessment estimates that the 100-year global warming potential (GWP) of CH<sub>4</sub> has increased by almost 9% relative to the estimates from AR4 (from 25 to 27.2), whereas the 100-year GWP of N<sub>2</sub>O has decreased by about 8% (from 298 to 273). Between AR4 and AR6 there was also a discussion of climate-carbon feedbacks. Including the climate-carbon feedback means taking into account the effect that a changing climate has on the carbon cycle. AR4 GWPs were calculated with climate-carbon feedbacks included for CO<sub>2</sub>, but not for non-CO<sub>2</sub> greenhouse gases. This inconsistent treatment of climate-carbon feedbacks can lead to underweighting the non-CO<sub>2</sub> greenhouse gases relative to their actual impacts. The publication of more studies using climate-carbon feedbacks for all gases, and the determination that a consistent approach was superior, led AR6 to include the climate-carbon feedbacks for all gases in the only GWP that was presented.

Another way of considering the impact of different greenhouse gases is to attribute the temperature changes of the last decade (2010-2019) to historical emissions of each gas. According to the AR6 assessment, historical emissions of carbon dioxide have contributed almost 0.8 degrees of warming to those temperatures, compared to about half a degree for historical emissions of CH<sub>4</sub>, and almost one tenth of a degree for historical emissions of N<sub>2</sub>O. These attributed temperature increases sum to more than the observed temperature change of almost 1.1 degrees because some of the warming is masked by various cooling influences, the most important of which is about half a degree of cooling resulting from historical emissions of sulfur dioxide.

## **A.2. Consumption Rate of Interest and Integration into Benefit-Cost Analysis**

When analyzing policies and programs that result in GHG emission reductions, it is important to account for the difference between the social and private rate of return on any capital investment affected by the action. Market distortions, such as taxes on capital income, cause private returns on capital investments to be different from the social returns. In well-functioning capital markets, arbitrage opportunities will be dissipated, and the cost of investments will equal the present value of future private returns on those investments. Therefore, an individual forgoing consumption or investment of equal amounts as the result of a regulation will face an equal private burden. However, because the social rate of return on the investment is greater than the private rate of return, the overall social burden will be greater in the case where investment is displaced. Thus, society is not indifferent between a regulation that displaces consumption versus investment in equal amounts.

OMB's Circular A-4 (2003) points out that "the analytically preferred method of handling temporal differences between benefits and costs is to adjust all the benefits and costs to reflect their value in equivalent units of consumption and to discount them at the rate consumers and savers would normally use in discounting future consumption benefits" (OMB 2003). Similarly, OMB's Circular A-4 (2023) points out that "The analytically preferred method of handling temporal differences between benefits and costs is to adjust all the benefits and costs to reflect their value in equivalent units of consumption before discounting them" (OMB 2023). The damage estimates developed for use in the SC-GHG are already estimated in consumption-equivalent terms. Therefore, an application of this OMB guidance would use the consumption discount rate to calculate the SC-GHG, while also developing a more complete estimate of social costs to account for the difference in private and social rates of return on capital for any investment displaced as a result of the action being analyzed. This more complete estimate of social costs could be developed using either the shadow price of capital approach or by estimating costs in a general

equilibrium framework, for example by using a computable general equilibrium model. In both cases, displaced investment would be converted into a flow of consumption equivalents that could be discounted at the consumption rate.

In cases where the costs are not adjusted to be in consumption-equivalent terms, OMB's Circular A-4 (2003) recommends that analysts provide a range of estimates for net benefits based on two approaches. The first approach is based on using the consumption rate of interest to discount all costs and benefits. This approach is consistent with the case where costs are primarily borne as reduced consumption. The second approach, the opportunity cost of capital approach, focuses on the case where the main effect of an action is to displace or alter the use of capital in the private sector (OMB 2003). When interpreting the opportunity cost of capital approach from the point of view of whether to invest in a single government project, it is asking whether the benefits from the project would at least match the returns from investing the same resources in the private sector. Interpreting the approach from the standpoint of a benefit-cost analysis of a regulation, the approach focuses on adjusting estimates of benefits downward by discounting at a higher rate to offset additional social costs not reflected in the private value of displaced investment used to develop the cost estimate (assuming the costs of the regulation are borne upfront).

Harberger (1972) derived a general version of the opportunity cost of capital approach, recognizing that policies will most likely displace a mix of consumption and investment and therefore, a blended discount rate would be needed to adjust the benefits to account for the omitted costs. In his partial equilibrium approach, the blended discount rate is a weighted average of the consumption interest rate and rate of return on capital, where the weights are the share of a policy's costs borne by consumption versus investment. This general result has been applied to the general equilibrium context by Sandmo and Drèze (1971) and Drèze (1974) and can be extended to account for changes in foreign direct investment (CEA 2017). This highlights that using the opportunity cost of capital to discount benefits and costs is, at best, creating a lower bound on the estimate of net benefits that would only be met in an extreme case where regulatory costs fully displace investment. If the beneficial impacts of the regulation induce private investment whose returns have not been quantified and fully converted to consumption equivalents, then this approach would not even be a lower bound, as the net benefits calculated using the opportunity cost of capital would be even lower than the theoretically correct lower bound.

An important limitation of the opportunity cost of capital approach is that its correct application depends heavily on the temporal patterns of the displaced capital returns and future benefits, including the lifetime of the displaced capital investment versus the lifetime of the benefit stream being valued (Li and Pizer 2021). In fact, using the opportunity cost of capital approach is only an accurate approximation of the correct shadow price of capital approach if these patterns are exactly the same. Li and Pizer (2021) show that a rate lower than the rate of return to capital is appropriate when displaced investment is relatively short-lived compared to the benefits stream and a higher rate is appropriate when displaced investment is relatively long-lived compared to benefits.

In benefit-cost analysis of policy actions whose benefits and costs occur over a relatively short time frame, the range of net benefits computed using the two discounting approaches may be relatively narrow. In this case, there may not be much error in presenting the opportunity cost of capital discounting approach side-by-side with consumption discounting as an effort to represent an uninformed prior over the share

of regulatory costs that will displace investment and using the potential bounding cases for net benefits. However, for cases where the costs are borne early in the time horizon and benefits occur for decades or even centuries, such as with GHG mitigation, the two estimates of net benefits will differ significantly. Importantly, in this circumstance, the opportunity cost of capital approach will substantially underestimate net benefits even for the case where the policy fully displaces investment. In this case, there is high risk of uninformative results from an analysis when using this two-discount-rate approach to provide an uninformed prior over the share of regulatory costs borne by investment. The preferred approach (OMB 2003, Li and Pizer 2021) is to develop more complete consumption-equivalent measure of costs and benefits, accounting for any effects on investment either by using a shadow price of capital approach or a general equilibrium framework, and then discounting those streams at the consumption rate of interest alone.

The "shadow price of capital" approach, described below, provides a method of ensuring that any additional social costs of displaced capital are accounted for in an analysis, as has been widely recognized in the academic literature (Lind 1990; Lyon 1990; Moore et al. 2013; Li and Pizer 2021) and in domestic and foreign government guidance documents (OMB 1972, 2003, 2023; EPA 2010; OECD 2018) as more appropriate than using the opportunity cost of capital approach. The most straightforward, although extreme, illustration of this approach is to consider the consumption value of a marginal dollar of displaced investment that persists forever. A permanent loss of investment is a very strong assumption because we would expect the displaced investment to be replaced eventually, but it is an instructive example of the approach. If this dollar had been invested, it would have earned a return on capital,  $r_i$ , every period into the future. If that yield was returned as consumption (or taxes that ultimately benefit households), the infinite stream of  $r_i$  should be discounted at the consumption rate of interest  $r_c$ . The present value of this infinite stream is  $r_i/r_c$ .<sup>164</sup> Under this strong assumption of a permanent displacement of capital, the shadow price of capital (SPC) would be calculated as the opportunity cost of capital divided by the consumption rate of interest. Because  $r_i > r_c$ , the SPC is greater than one, reflecting the additional cost of the displaced capital. Multiplying any portion of costs (and/or benefits) that affect investment in this way, and then discounting using the consumption rate of interest would appropriately account for the displaced investment.

However,  $r_i/r_c$  would only be the correct SPC to use in the extreme case where changes in the productive capital stock persist in perpetuity. A more realistic version of the SPC accounts for how savings and depreciation cause the impact of displaced capital to dissipate in the future. In particular, with a savings (or reinvestment) rate of  $s$  from gross income and a depreciation rate of  $\mu$ , an invested dollar returns  $(1 - s)(r_i + \mu)$  in consumption in the first period. Each period after that, the amount of investment that continues to be displaced is determined by the savings rate, assuming a closed economy. However, the invested capital also declines according to the depreciation rate. This creates a stream of consumption benefits equal to

$$C_t = \sum_{t=0}^{\infty} (1 - s)(r_i + \mu)[1 + s(r_i + \mu) - \mu]^t, \quad (A.2.1)$$

<sup>164</sup> An infinite stream of return is a type of annuity called a perpetuity. The present value of a perpetuity,  $r_i$ , that begins in year 1 and is discounted at a rate of  $r_c$  is  $PV = \frac{r_i}{(1+r_c)} + \frac{r_i}{(1+r_c)^2} + \frac{r_i}{(1+r_c)^3} + \dots = \frac{r_i}{r_c}$ . That is, the present value of a perpetuity is the annual return,  $r_i$ , divided by the rate of discount,  $r_c$ .

which is discounted at the consumption discount rate  $r_c$ . Including constant savings and depreciation rates yields a shadow price of capital<sup>165</sup> equal to

$$SPC = \frac{(1-s)(r_i + \mu)}{r_c + \mu - s(r_i + \mu)} \quad (A.2.2)$$

Equation A.2.2 can be updated to include a capital tax rate that explicitly defines a difference between  $r_i$  and  $r_c$ , but the result of the analysis would not change if the tax revenue was used to benefit society.<sup>166</sup> In the analysis, the portion of costs (and/or benefits) that displace investment would be multiplied by the SPC to adjust for any missing social impacts and then all costs and benefits would be discounted at the consumption rate of interest.

Estimates of the closed economy SPC in the academic literature are in the range of 1.1 to 2.2 (Groom et al. 2005, Boardman et al. 2010, Moore et al. 2013, Li and Pizer 2021). In an open economy model the SPC may be closer to 1.0 (Lind 1990). OMB's Circular A-4 (2023) recommends "consideration of a lower value of 1.0, reflecting an economy with perfect capital mobility ... and a high value of 1.2, reflecting a closed economy with no foreign capital flows." Independent of the value used, implementing this approach in practice can be challenging because it requires an assessment of the portion of costs (and/or benefits) that displace investment. OMB's Circular A-4 (2023) notes that "[i]f the incidence of benefits and costs falling on capital are not directly estimated, one approach is to test your analysis's sensitivity to assumptions about the incidence of regulatory effects on capital by analyzing two outer-bound cases: one assuming all benefits and no costs fall on capital, and another assuming all costs and no benefits fall on capital."

### A.3. Derivations of the SC-GHG Values for use in Analyses

This report presents SC-GHG estimates as certainty-equivalent values that account for the uncertainty (a range of possible outcomes) in future consumption underlying the RFF-SP probabilistic growth scenarios. To recover a discounted present value of climate damages from future emissions, analysts consider the

<sup>165</sup> When including depreciation,  $\mu$ , the gross return on a capital stock  $k_0$  will be  $(r_i + \mu)k_0$ , where  $\mu$  is the depreciation rate. With a savings or reinvestment rate of  $s$ , a capital stock of  $k_0$  in period 0 will return  $(1-s)(r_i + \mu)k_0$  as consumption and  $s(r_i + \mu)k_0$  will be saved for reinvestment. In period 1, the capital stock will be the original capital less depreciation, plus the amount reinvested,  $k_1 = \{(1-\mu)k_0\} + \{s(r_i + \mu)k_0\} = [1 + s(r_i + \mu) - \mu]k_0$ . This will return  $(1-s)(r_i + \mu)[1 + s(r_i + \mu) - \mu]k_0$  as consumption in period 1 and  $s(r_i + \mu)[1 + s(r_i + \mu) - \mu]k_0$  will be reinvested. The capital stock in period 2 will be  $k_2 = \{(1-\mu)[1 + s(r_i + \mu) - \mu]k_0\} + \{s(r_i + \mu)[1 + s(r_i + \mu) - \mu]k_0\} = [1 + s(r_i + \mu) - \mu]^2 k_0$ , which will return  $(1-s)(r_i + \mu)[1 + s(r_i + \mu) - \mu]^2 k_0$  as consumption. This creates an infinite consumption stream of  $C = (1-s)(r_i + \mu)k_0 + (1-s)(r_i + \mu)[1 + s(r_i + \mu) - \mu]k_0 + (1-s)(r_i + \mu)[1 + s(r_i + \mu) - \mu]^2 k_0 + \dots$  This is a perpetuity of  $[(1-s)(r_i + \mu)k_0]$  with a growth rate of  $[s(r_i + \mu) - \mu]$ , and should be discounted at the consumption rate of discount  $r_c$ . The present value of perpetuity  $A$ , growing at a rate of  $g$ , and discounted at rate  $r$  is  $PV = \frac{A}{(1+r)} + \frac{A(1+g)}{(1+r)^2} + \frac{A(1+g)^2}{(1+r)^3} + \dots = \frac{A}{(r-g)}$ . So, the present value of the perpetuity described above would be  $PV = \frac{(1-s)(r_i + \mu)k_0}{(r_c - [s(r_i + \mu) - \mu])} = \frac{(1-s)(r_i + \mu)}{r_c + \mu - s(r_i + \mu)} k_0$ .

<sup>166</sup> If a portion of the tax revenues affect investments, then it requires an analogous adjustment to account for the fact that it creates a current period consumption value greater than one according to the "marginal value of public funds,"  $v_G$ . In this case, the numerator in the SPC equation would be equal to  $(1-s)(r_i + \mu) + (v_G - 1)\tau r_i$ , where  $\tau$  is the tax rate on capital (Li and Pizer 2021).

SC-GHG associated with future emissions and then discount that value to the year of their analysis. For example, an analyst interested in the present value in the year 2022 of changes in future emissions in the year 2030 would use the 2030 SC-GHG and discount back to recover a present value in the year 2022. However, there is uncertainty in future consumption, and the analyst should account for the range of possible outcomes. This is because risk-averse agents value the costs of future emissions differently than risk-neutral agents by accounting for these uncertain outcomes. There are several ways to account for this uncertainty. The approach taken in this report is to provide certainty-equivalent SC-GHG values that can be easily used by analysts with a conventional discounting approach, as described in Section 4.2. This section describes the equations used to recover those certainty-equivalent SC-GHG estimates for an emissions year  $\tau$ , denoted as  $scghg_{\tau}$ .

We begin with a motivating example of how the SC-GHG estimates in this report should be used in regulatory analysis. Imagine a hypothetical regulation in year  $t_0$  that reduces  $x_{\tau}$  tons of greenhouse gas emissions in the future years 2030 through 2050. An analyst wants to calculate the present value in year  $t_0$ ,  $pv_{t_0}$ , of the regulation's benefits from these future reductions in greenhouse gas emissions. To do so, the analyst should multiply the emission reduction in each year,  $x_{\tau}$ , times the SC-GHG estimates found in this report for each of those years, discount these products back to the present using the certainty-equivalent discount rate  $\tilde{r}_{\tau}$  for each emissions year  $\tau$ , and then sum the values. Denote the SC-GHG estimates found in this report as  $scghg_{\tau}$ , where  $\tau$  is the year of emissions, 2030 through 2050. The analyst then calculates the present value of the regulation's benefits as

$$pv_{t_0} = \sum_{\tau=2030}^{2050} x_{\tau} \cdot scghg_{\tau} \cdot e^{-\tilde{r}_{\tau}(\tau-t_0)}. \quad (A.3.1)$$

In other words, the  $scghg_{\tau}$  values presented in this report yield the present value when discounted using the certainty-equivalent discount factor  $e^{-\tilde{r}_{\tau}(\tau-t_0)}$ . This discount factor was written as  $\tilde{\delta}_{\tau}$  in Section 4.2 but is defined in more detail below.

The remainder of this section describes the derivation of the certainty-equivalent SC-GHG,  $scghg_{\tau}$ . For notational convenience, we use index years and assume that the present is year  $t_0 = 0$ . The certainty-equivalent discount factor in the Ramsey framework for year  $t$  is

$$e^{-t \cdot \tilde{r}_t} = E[e^{-\sum_{s=0}^t (\rho + \eta g_s)}], \quad (A.3.2)$$

where  $\tilde{r}_t$  is the certainty-equivalent discount rate. This is the single, time-averaged discount rate that produces the same discount factor over a specific time horizon as the distribution of uncertain discount rates. This certainty-equivalent discount rate is defined as

$$\tilde{r}_t = \rho - \left(\frac{1}{t}\right) \left( \ln E \left[ e^{-\sum_{s=0}^t (\eta g_s)} \right] \right) = \rho + \left(\frac{1}{t}\right) E \left[ \ln \left( \frac{c_t}{c_0} \right)^{\eta} \right] \quad (A.3.3)$$

and

$$e^{-t \cdot \tilde{r}_t} = e^{-t \cdot \left[ \rho + \left( \frac{1}{t} \right) E \left[ \ln \left( \frac{c_t}{c_0} \right)^\eta \right] \right]} = e^{-t \cdot \rho} \cdot E \left[ \left( \frac{c_t}{c_0} \right)^{-\eta} \right] = E \left[ \left( \frac{1}{1 + \tilde{\rho}} \right)^t \cdot \left( \frac{c_t}{c_0} \right)^{-\eta} \right]. \quad (A.3.4)$$

Here, as described in Section 3.4,  $r_t$  is the consumption discount rate in year  $t$ ,  $\rho$  is the pure rate of time preference, and  $\eta$  is the elasticity of marginal utility with respect to consumption.  $c_t$  is the representative agent's year  $t$  consumption, and  $g_t = \ln \left( \frac{c_t}{c_0} \right)$  is the consumption growth rate for year  $t$ . Importantly,  $c_t$  is consumption *net of climate change damages*. Also,  $\tilde{\rho} = e^\rho - 1$  is the discrete annual pure rate of time preference.

Consider the present value at  $t = 0$  of a stream of marginal damages  $md_t$  from a single emissions year  $\tau$ . The  $scghg_0$  is the present value of the social cost of GHG emissions from marginal damages from year  $t = 0$  to the end of the analysis period,  $T$ , and is given by

$$scghg_0 = \sum_{t=0}^T E \left[ \frac{1}{(1 + \tilde{\rho})^t} \left( \frac{c_t}{c_0} \right)^{-\eta} md_t \right]. \quad (A.3.5)$$

Because year  $\tau$  is in the future,  $md_t = 0$  for  $t = 0$  to  $\tau$ .<sup>167</sup>

Now consider the SC-GHG values presented in this report,  $scghg_\tau$ , for the same stream of marginal damages  $md_t$  from an emissions in year  $\tau$  in the future. According to Equation (A.3.1), the present value  $scghg_0$  for any emission year  $\tau$  should also be equal to the  $scghg_\tau$  discounted back to current period  $t = 0$  using the certainty-equivalent discount rate<sup>168</sup>

$$scghg_0 = scghg_\tau \cdot E \left[ \frac{1}{(1 + \tilde{\rho})^\tau} \left( \frac{c_\tau}{c_0} \right)^{-\eta} \right]. \quad (A.3.6)$$

So

$$scghg_\tau = \frac{scghg_0}{E \left[ \frac{1}{(1 + \tilde{\rho})^\tau} \left( \frac{c_\tau}{c_0} \right)^{-\eta} \right]} = \sum_{t=0}^T \frac{E \left[ \frac{1}{(1 + \tilde{\rho})^t} \left( \frac{c_t}{c_0} \right)^{-\eta} md_t \right]}{E \left[ \frac{1}{(1 + \tilde{\rho})^\tau} \left( \frac{c_\tau}{c_0} \right)^{-\eta} \right]}. \quad (A.3.7)$$

Assuming that consumption is certain in the present year ( $t = 0$ ),  $c_0$  can be canceled, and

$$scghg_\tau = \sum_{t=0}^T \frac{E \left[ \frac{1}{(1 + \tilde{\rho})^t} (c_t)^{-\eta} md_t \right]}{E \left[ \frac{1}{(1 + \tilde{\rho})^\tau} (c_\tau)^{-\eta} \right]}. \quad (A.3.8)$$

Simplifying this expression yields

<sup>167</sup> Technically,  $scghg_0$  and  $md_t$  should be subscripted as  $scghg_{0,\tau}$  and  $md_{t,\tau}$  because they are conditional on the future emissions year  $\tau$ .

<sup>168</sup> Recall that we have switched from calendar years to index years so  $t_0 = 0$  and, in this case, there is only one emission year,  $\tau$ .

$$scghg_{\tau} = \frac{1}{E[(c_{\tau})^{-\eta}]} \sum_{t=0}^T E \left[ \frac{1}{(1 + \tilde{\rho})^{t-\tau}} (c_t)^{-\eta} md_t \right]. \quad (A.3.9)$$

Note that Equation (A.3.9) is not the same as simply discounting the marginal damages back to the year of emissions (year  $\tau$ ), which would be the expected value

$$scghg'_{\tau} = \sum_{t=\tau}^T E \left[ \frac{1}{(1 + \tilde{\rho})^{t-\tau}} \left( \frac{c_t}{c_{\tau}} \right)^{-\eta} md_t \right]. \quad (A.3.10)$$

The  $scghg_{\tau}$  estimates based on the GIVE model (Rennert et al. 2022b) and the Meta-Analysis (Howard and Sterner 2017) are directly estimated using Equation (A.3.9). The  $scghg_{\tau}$  estimates under the DSCIM damage module, however, are adjusted post-estimation to exactly equal Equation (A.3.9). The remainder of this section describes this adjustment alongside its analogue for GIVE. Consider trial  $i$ , year  $t$ , emissions year  $\tau$ , net consumption per capita  $c_{i,t}$ , and marginal damages  $md_{i,t,\tau}$ . A trial  $i$  is a unique socioeconomic pathway, FaIR1.6.2 climate scenario, and random damage parameter pairing. For each trial, GIVE estimates

$$scghg_{i,\tau} = \frac{\sum_{t=\tau}^{2300} \left( \frac{1}{c_{i,t}} \right)^{\eta} \frac{1}{(1 + \tilde{\rho})^{t-\tau}} md_{i,t}}{E[c_{\tau}^{-\eta}]}, \quad (A.3.11)$$

and the  $scghg_{\tau}$  from Equation (A.3.9) results from applying the expectation operator to Equation (A.3.11).

In contrast to Equation (A.3.11), DSCIM estimates

$$scghg_{i,\tau}^{DSCIM} = \sum_{t=\tau}^{2300} \left( \frac{c_{i,\tau}}{c_{i,t}} \right)^{\eta} \frac{1}{(1 + \tilde{\rho})^{t-\tau}} md_{i,t}. \quad (A.3.12)$$

Equations (A.3.11) and (A.3.12) can be equated by

$$scghg_{i,\tau} = \frac{1}{c_{i,\tau}^{\eta} E[c_{\tau}^{-\eta}]} scghg_{i,\tau}^{DSCIM}. \quad (A.3.13)$$

The first expression on the right-hand side of Equation (A.3.13) is the adjustment factor that is used to convert the values provided by DSCIM for use in the report. This adjustment equation is trial-specific, so the values presented in this report are the means across trials (i.e., applying an expectation operator to Equation (A.3.11)).

The full derivation of a certainty-equivalent discount rate path involves damage-module-specific net consumption paths, damage-module-specific SC-GHG estimates, and a unique certainty-equivalent rate path for each analysis year. However, as noted in Section 4.2, the error associated with using a constant discount rate rather than the certainty-equivalent rate path (i.e.,  $E \left[ \frac{1}{(1 + \tilde{\rho})^{\tau}} \left( \frac{c_{\tau}}{c_0} \right)^{-\eta} \right]$  in Equation (A.3.6)) to calculate the present value of a future stream of monetized climate benefits is small for analyses with

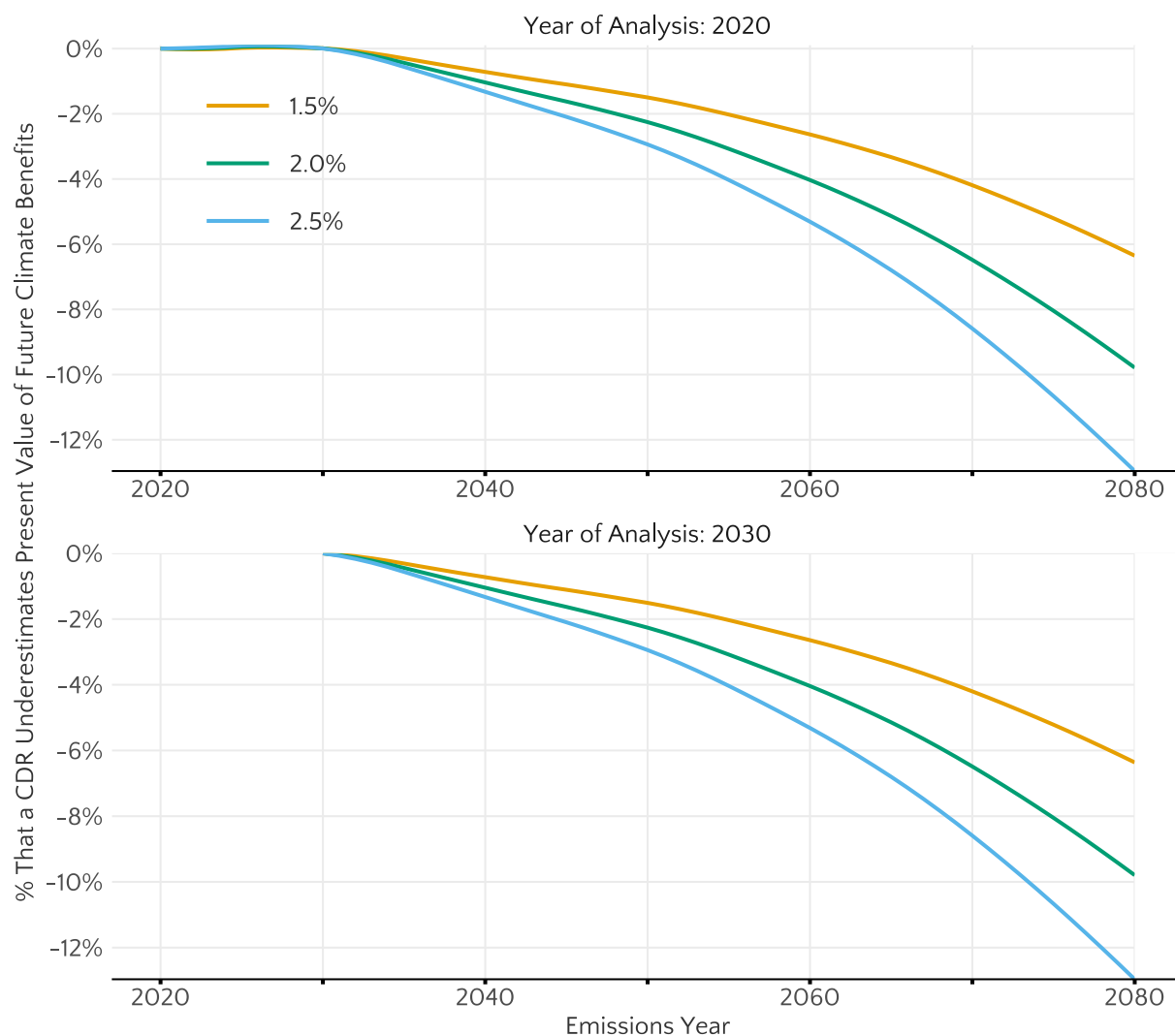


moderate time frames (e.g., 30 years or less). In other words, for analyses with a moderate time frame, the present value of the regulation's benefits can be calculated as

$$pv_{t_0} = \sum_{\tau=2030}^{2050} x_{\tau} \cdot scghg_{\tau} \cdot e^{-\bar{r}(\tau-t_0)}, \quad (A.3.14)$$

where  $\bar{r}$  is simply the near-term (2.5%, 2%, and 1.5%) corresponding to the SC-GHG value used. Figure A.3.1 provides an illustration of the amount that climate benefits from reductions in future emissions will be underestimated by using a constant discount rate relative to the more complicated certainty-equivalent rate path.

**Figure A.3.1 The Difference Between using a Certainty-Equivalent Rate and Constant Discount Rate to Discount Climate Benefits from Future Reductions in GHG Emissions Back to the Year of the Analysis**



When using a constant discount rate (CDR) to discount climate benefits from future GHG emissions reductions back to the year of the analysis, the resulting present value of climate benefits will be underestimated (i.e., future emissions reductions will be valued using a lower SC-GHG than they would be if the analyst used a certainty-equivalent rate (CER) to discount those same future emission reductions). The lines represent the average percent that these future values would be undervalued at three near-term Ramsey discount rates. For example, if the analyst discounts the monetized value of a 2080 emissions reduction back to the year 2030 using a constant discount rate (i.e., 2.5%, 2%, or 1.5%) as shown in the middle panel, that present value would be approximately 13% lower than when using the 2.5% CER, 10% lower than when using the 2% CER, and 6% lower than when using the 1.5% CER.

## A.4. The Climate Beta

The climate beta is a measure of the covariance between consumption growth and marginal climate change damages. This can similarly be viewed as the covariance between the returns to climate mitigation investments and future consumption growth. According to the asset pricing literature (see discussions in, e.g., Gollier 2014, Dietz et al. 2018, Howard and Schwartz 2022, Prest 2023), if climate damages are positively correlated with consumption growth, then the returns to climate mitigation investments pay off more in states of the world with higher consumption levels.<sup>169</sup> In this case, climate damages should be discounted at a higher rate than the risk-free rate. As discussed in Section 2, the possibility that climate-related damages are positively correlated with market returns was the motivation for using a higher 5% discount rate in the SC-GHG estimates produced by the IWG in 2010. If, on the other hand, climate damages are negatively correlated with consumption growth, then climate mitigation investments pay off more in states of the world with relatively lower levels of consumption, and they should be discounted at a lower rate than the risk-free rate because it provides some insurance against the bad economic outcome (Howard and Schwartz 2022, Lemoine 2021).

The concept of the climate beta is based on the Consumption-based Capital Asset Pricing Model (CCAPM) literature (Lucas 1978, Cochrane 2009). In the CCAPM, the expected return of any asset  $E(R^i)$ , is equal to the risk-free rate of return plus a risk adjustment. That is,

$$E[R^i] = R^f + \beta(E[R^m] - R^f), \quad (\text{A.4.1})$$

where  $R^f$  is the risk-free rate of return,  $R^m$  is the average return of the market, and  $(E[R^m] - R^f)$  is the market risk premium, which is the difference between the average market rate of return and the risk-free rate of return.<sup>170</sup> The beta,  $\beta$ , is the slope of a linear relationship between the risk adjusted rate of return and the market risk premium.

In the case of a risk-free asset,  $\beta = 0$ . Any future payoff from a risk-free asset should be discounted at the risk-free rate of return,  $R^f$ . If an asset has the exact same risk profile as that of the average market, then  $\beta = 1$ . Any future payoff from this asset should be discounted at the average market rate of return,  $E[R^m]$ . Assets that are more strongly correlated with overall market returns have a  $\beta > 1$  and are discounted at a higher rate than risk-free assets to compensate for their risk profile. Similarly, assets that are negatively correlated with market returns have a  $\beta < 1$  and are discounted at a rate less than the risk-free rate.  $R^i$  is the risk-adjusted rate of return because it accounts for the idiosyncratic risk inherent in the particular asset. Equation (A.4.1) can be used to estimate the risk-adjusted discount rate for any asset given  $R^f$ ,  $E[R^m]$ , and an estimate of its  $\beta$ .

In the climate context, the assets being valued are marginal climate damages or, conversely, marginal benefits of climate mitigation. The market return, to which the returns to climate mitigation are being compared in the CCAPM, is consumption growth net of baseline climate damages. The climate beta

<sup>169</sup> The economic framework in this report implicitly assumes an exogenous fixed savings rate. With this assumption, consumption growth and income (GDP) growth are equivalent. A more restrictive assumption that leads to the same result would be to assume that the savings rate is zero and consumption is equivalent to income. Relaxing the fixed savings rate assumption would require adding further complexity to calculate the optimal savings rate in each year.

<sup>170</sup> The CCAPM is known to underestimate the risk premia in financial markets, which is commonly referred to as the equity premium puzzle (see, for example, Gollier (2013) for a discussion).

reflects the relationship between the rate of marginal climate damages and the rate of consumption growth (Dietz et al. 2018).

In the SC-GHG model runs presented in this report, the climate beta is not a choice variable. The relationship between consumption growth and climate damages, which defines the climate beta, is internally determined by the relationship between the socioeconomic and emissions, climate, and damage modules. That is, each trial has its own growth path, and each year in the trial has its own growth rate from the previous year. Because the discount rate is increasing in  $g_t$  (when  $\eta > 0$ ), scenarios with higher growth rates will have higher discount rates and vice versa. Because both consumption growth and marginal damages for each year and Monte Carlo trial is included inside the expectations operator of Equation A.3.5, the correlation between them is incorporated in the SC-GHG estimate. Prest (2023) shows that this approach addresses uncertainty in consumption growth and its correlation with climate damages within the CCAPM.

For the SC-GHG estimates in this report, the implied climate beta can be estimated by regressing the log of the absolute value of marginal damages on the log of per capita consumption (net of baseline climate damages) (Dietz et al. 2018, Prest 2023).<sup>171</sup> Using this approach the annual climate beta for each of the three damage modules is estimated separately and for all damage modules combined, using the marginal damages for a 2030 emissions year. The average beta for 2031-2300 is 0.92 for DSCIM, 0.88 for GIVE, and 0.98 for the meta-analysis. In the DSCIM and GIVE model runs, the climate beta increases over time after 2050, and in the meta-analysis-based run it declines over time. The climate beta in 2050 is 0.68, 0.84, and 0.99 for DSCIM, GIVE, and the meta-analysis, respectively, and the climate beta in 2300 is 0.99, 0.92, and 0.97. Combining the marginal damages from all damage modules produces an implied climate beta of 0.92 for 2031-2300, rising from 0.83 in 2050 to 0.96 in 2300. The implied climate beta for CH<sub>4</sub> and N<sub>2</sub>O is similar for each of the three damage modules. The positive climate beta implies a positive risk premium for climate investments and that damages in each trial year are discounted at a risk-adjusted rate that is higher than the risk-free rate. Prest (2023) calculates the risk premia for the GIVE damage module used in this report over the 2020-2300 time horizon and finds an average risk premium for climate investments of 1.3%. The certainty equivalent discount rates shown in Figure 2.4.1 decline over the time horizon, but Prest (2023) finds that the risk premia above the certainty equivalent rates increase over the time horizon to 2.7% around 2300 for the GIVE damage module.

The positive implied climate beta based on the modular framework used in this report indicates that the risk-adjusted discount rate is higher than the risk-free rate. As described above, risk is incorporated through the Ramsey formula to discount the marginal climate damages from the three damage modules for each simulation. While this estimated climate beta is consistent with some literature (Dietz et al. 2018, Prest 2023), there are very few empirical estimates to compare it to. Estimates of the climate beta based

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<sup>171</sup> If marginal damages are all positive values, then the implied beta can be obtained by regressing the logarithm of marginal damages on the log of net per capita consumption (Dietz et al. 2018). However, this approach must be modified if there are negative values (i.e., if increased emissions are associated with negative marginal damages, or marginal benefits). While there are marginal benefits associated with increases in global temperatures (e.g., decreased mortality from cold-related impacts), the vast majority of the Monte Carlo trials in the three models show positive marginal damages. However, all three damage modules contain some draws with negative values. This issue is addressed by regressing the logarithm of the absolute value of marginal damages on the log of net per capita consumption, following Prest (2023).

on IAM results are necessarily a function of the structural form of the damage function and its implications for the correlation between consumption and climate damages. For example, the meta-analysis damage function used in this report assumes that damages are proportional to GDP, which implies a high degree of correlation. Howard and Schwartz (2022) identify several reasons why the climate beta may be lower than currently estimated in the literature—and could theoretically be negative—including: if climate change has a persistent negative effect on economic growth; if climate tipping points alter the proportional relationship between GDP and climate damages; if climate adaptation increases with income; or if omitted climate damages are higher in regions with lower GDP or in sectors that contribute less to GDP. As discussed in Section 3.2, some of these features are not currently accounted for within the framework used in this report. EPA will continue to follow scientific advances that allow for improvements in the SC-GHG modeling framework and their implications for the implied climate beta in future SC-GHG updates.

## A.5. Annual Unrounded SC-CO<sub>2</sub>, SC-CH<sub>4</sub>, and SC-N<sub>2</sub>O Values, 2020-2080

Table A.5.1: Unrounded SC-CO<sub>2</sub>, SC-CH<sub>4</sub>, and SC-N<sub>2</sub>O Values, 2020-2080

| Emission<br>Year | SC-GHG and Near-term Ramsey Discount Rate                               |      |      |                                                                         |       |       |                                                                          |        |         |
|------------------|-------------------------------------------------------------------------|------|------|-------------------------------------------------------------------------|-------|-------|--------------------------------------------------------------------------|--------|---------|
|                  | SC-CO <sub>2</sub><br>(2020 dollars per metric ton of CO <sub>2</sub> ) |      |      | SC-CH <sub>4</sub><br>(2020 dollars per metric ton of CH <sub>4</sub> ) |       |       | SC-N <sub>2</sub> O<br>(2020 dollars per metric ton of N <sub>2</sub> O) |        |         |
|                  | Near-term rate                                                          |      |      | Near-term rate                                                          |       |       | Near-term rate                                                           |        |         |
|                  | 2.5%                                                                    | 2.0% | 1.5% | 2.5%                                                                    | 2.0%  | 1.5%  | 2.5%                                                                     | 2.0%   | 1.5%    |
| 2020             | 117                                                                     | 193  | 337  | 1,257                                                                   | 1,648 | 2,305 | 35,232                                                                   | 54,139 | 87,284  |
| 2021             | 119                                                                     | 197  | 341  | 1,324                                                                   | 1,723 | 2,391 | 36,180                                                                   | 55,364 | 88,869  |
| 2022             | 122                                                                     | 200  | 346  | 1,390                                                                   | 1,799 | 2,478 | 37,128                                                                   | 56,590 | 90,454  |
| 2023             | 125                                                                     | 204  | 351  | 1,457                                                                   | 1,874 | 2,564 | 38,076                                                                   | 57,816 | 92,040  |
| 2024             | 128                                                                     | 208  | 356  | 1,524                                                                   | 1,950 | 2,650 | 39,024                                                                   | 59,041 | 93,625  |
| 2025             | 130                                                                     | 212  | 360  | 1,590                                                                   | 2,025 | 2,737 | 39,972                                                                   | 60,267 | 95,210  |
| 2026             | 133                                                                     | 215  | 365  | 1,657                                                                   | 2,101 | 2,823 | 40,920                                                                   | 61,492 | 96,796  |
| 2027             | 136                                                                     | 219  | 370  | 1,724                                                                   | 2,176 | 2,910 | 41,868                                                                   | 62,718 | 98,381  |
| 2028             | 139                                                                     | 223  | 375  | 1,791                                                                   | 2,252 | 2,996 | 42,816                                                                   | 63,944 | 99,966  |
| 2029             | 141                                                                     | 226  | 380  | 1,857                                                                   | 2,327 | 3,083 | 43,764                                                                   | 65,169 | 101,552 |
| 2030             | 144                                                                     | 230  | 384  | 1,924                                                                   | 2,403 | 3,169 | 44,712                                                                   | 66,395 | 103,137 |
| 2031             | 147                                                                     | 234  | 389  | 2,002                                                                   | 2,490 | 3,270 | 45,693                                                                   | 67,645 | 104,727 |
| 2032             | 150                                                                     | 237  | 394  | 2,080                                                                   | 2,578 | 3,371 | 46,674                                                                   | 68,895 | 106,316 |
| 2033             | 153                                                                     | 241  | 398  | 2,157                                                                   | 2,666 | 3,471 | 47,655                                                                   | 70,145 | 107,906 |
| 2034             | 155                                                                     | 245  | 403  | 2,235                                                                   | 2,754 | 3,572 | 48,636                                                                   | 71,394 | 109,495 |
| 2035             | 158                                                                     | 248  | 408  | 2,313                                                                   | 2,842 | 3,673 | 49,617                                                                   | 72,644 | 111,085 |
| 2036             | 161                                                                     | 252  | 412  | 2,391                                                                   | 2,929 | 3,774 | 50,598                                                                   | 73,894 | 112,674 |
| 2037             | 164                                                                     | 256  | 417  | 2,468                                                                   | 3,017 | 3,875 | 51,578                                                                   | 75,144 | 114,264 |
| 2038             | 167                                                                     | 259  | 422  | 2,546                                                                   | 3,105 | 3,975 | 52,559                                                                   | 76,394 | 115,853 |
| 2039             | 170                                                                     | 263  | 426  | 2,624                                                                   | 3,193 | 4,076 | 53,540                                                                   | 77,644 | 117,443 |
| 2040             | 173                                                                     | 267  | 431  | 2,702                                                                   | 3,280 | 4,177 | 54,521                                                                   | 78,894 | 119,032 |
| 2041             | 176                                                                     | 271  | 436  | 2,786                                                                   | 3,375 | 4,285 | 55,632                                                                   | 80,304 | 120,809 |
| 2042             | 179                                                                     | 275  | 441  | 2,871                                                                   | 3,471 | 4,394 | 56,744                                                                   | 81,714 | 122,586 |
| 2043             | 182                                                                     | 279  | 446  | 2,955                                                                   | 3,566 | 4,502 | 57,855                                                                   | 83,124 | 124,362 |
| 2044             | 186                                                                     | 283  | 451  | 3,040                                                                   | 3,661 | 4,610 | 58,966                                                                   | 84,535 | 126,139 |
| 2045             | 189                                                                     | 287  | 456  | 3,124                                                                   | 3,756 | 4,718 | 60,078                                                                   | 85,945 | 127,916 |
| 2046             | 192                                                                     | 291  | 462  | 3,209                                                                   | 3,851 | 4,827 | 61,189                                                                   | 87,355 | 129,693 |
| 2047             | 195                                                                     | 296  | 467  | 3,293                                                                   | 3,946 | 4,935 | 62,301                                                                   | 88,765 | 131,469 |
| 2048             | 199                                                                     | 300  | 472  | 3,378                                                                   | 4,041 | 5,043 | 63,412                                                                   | 90,176 | 133,246 |
| 2049             | 202                                                                     | 304  | 477  | 3,462                                                                   | 4,136 | 5,151 | 64,523                                                                   | 91,586 | 135,023 |
| 2050             | 205                                                                     | 308  | 482  | 3,547                                                                   | 4,231 | 5,260 | 65,635                                                                   | 92,996 | 136,799 |

*Table A.5.1: Unrounded SC-CO<sub>2</sub>, SC-CH<sub>4</sub>, and SC-N<sub>2</sub>O Values, 2020-2080 (continued...)*

| Emission<br>Year | SC-GHG and Near-term Ramsey Discount Rate                               |      |      |                                                                         |       |       |                                                                          |         |         |
|------------------|-------------------------------------------------------------------------|------|------|-------------------------------------------------------------------------|-------|-------|--------------------------------------------------------------------------|---------|---------|
|                  | SC-CO <sub>2</sub><br>(2020 dollars per metric ton of CO <sub>2</sub> ) |      |      | SC-CH <sub>4</sub><br>(2020 dollars per metric ton of CH <sub>4</sub> ) |       |       | SC-N <sub>2</sub> O<br>(2020 dollars per metric ton of N <sub>2</sub> O) |         |         |
|                  | 2.5%                                                                    | 2.0% | 1.5% | 2.5%                                                                    | 2.0%  | 1.5%  | 2.5%                                                                     | 2.0%    | 1.5%    |
| 2051             | 208                                                                     | 312  | 487  | 3,624                                                                   | 4,320 | 5,363 | 66,673                                                                   | 94,319  | 138,479 |
| 2052             | 211                                                                     | 315  | 491  | 3,701                                                                   | 4,409 | 5,466 | 67,712                                                                   | 95,642  | 140,158 |
| 2053             | 214                                                                     | 319  | 496  | 3,779                                                                   | 4,497 | 5,569 | 68,750                                                                   | 96,965  | 141,838 |
| 2054             | 217                                                                     | 323  | 500  | 3,856                                                                   | 4,586 | 5,672 | 69,789                                                                   | 98,288  | 143,517 |
| 2055             | 220                                                                     | 326  | 505  | 3,933                                                                   | 4,675 | 5,774 | 70,827                                                                   | 99,612  | 145,196 |
| 2056             | 222                                                                     | 330  | 510  | 4,011                                                                   | 4,763 | 5,877 | 71,866                                                                   | 100,935 | 146,876 |
| 2057             | 225                                                                     | 334  | 514  | 4,088                                                                   | 4,852 | 5,980 | 72,904                                                                   | 102,258 | 148,555 |
| 2058             | 228                                                                     | 338  | 519  | 4,165                                                                   | 4,941 | 6,083 | 73,943                                                                   | 103,581 | 150,235 |
| 2059             | 231                                                                     | 341  | 523  | 4,243                                                                   | 5,029 | 6,186 | 74,981                                                                   | 104,904 | 151,914 |
| 2060             | 234                                                                     | 345  | 528  | 4,320                                                                   | 5,118 | 6,289 | 76,020                                                                   | 106,227 | 153,594 |
| 2061             | 236                                                                     | 348  | 532  | 4,389                                                                   | 5,199 | 6,385 | 76,920                                                                   | 107,385 | 155,085 |
| 2062             | 239                                                                     | 351  | 535  | 4,458                                                                   | 5,280 | 6,480 | 77,820                                                                   | 108,542 | 156,576 |
| 2063             | 241                                                                     | 354  | 539  | 4,527                                                                   | 5,361 | 6,576 | 78,720                                                                   | 109,700 | 158,066 |
| 2064             | 244                                                                     | 357  | 543  | 4,596                                                                   | 5,442 | 6,671 | 79,620                                                                   | 110,857 | 159,557 |
| 2065             | 246                                                                     | 360  | 547  | 4,666                                                                   | 5,523 | 6,767 | 80,520                                                                   | 112,015 | 161,048 |
| 2066             | 248                                                                     | 363  | 550  | 4,735                                                                   | 5,604 | 6,862 | 81,419                                                                   | 113,172 | 162,539 |
| 2067             | 251                                                                     | 366  | 554  | 4,804                                                                   | 5,685 | 6,958 | 82,319                                                                   | 114,330 | 164,030 |
| 2068             | 253                                                                     | 369  | 558  | 4,873                                                                   | 5,765 | 7,053 | 83,219                                                                   | 115,487 | 165,521 |
| 2069             | 256                                                                     | 372  | 562  | 4,942                                                                   | 5,846 | 7,149 | 84,119                                                                   | 116,645 | 167,012 |
| 2070             | 258                                                                     | 375  | 565  | 5,011                                                                   | 5,927 | 7,244 | 85,019                                                                   | 117,802 | 168,503 |
| 2071             | 261                                                                     | 378  | 569  | 5,085                                                                   | 6,013 | 7,344 | 86,012                                                                   | 119,027 | 170,013 |
| 2072             | 263                                                                     | 382  | 573  | 5,160                                                                   | 6,099 | 7,444 | 87,006                                                                   | 120,252 | 171,523 |
| 2073             | 266                                                                     | 385  | 576  | 5,234                                                                   | 6,184 | 7,545 | 87,999                                                                   | 121,477 | 173,033 |
| 2074             | 269                                                                     | 388  | 580  | 5,309                                                                   | 6,270 | 7,645 | 88,992                                                                   | 122,702 | 174,543 |
| 2075             | 271                                                                     | 391  | 583  | 5,383                                                                   | 6,355 | 7,745 | 89,985                                                                   | 123,926 | 176,053 |
| 2076             | 274                                                                     | 394  | 587  | 5,458                                                                   | 6,441 | 7,845 | 90,978                                                                   | 125,151 | 177,563 |
| 2077             | 276                                                                     | 398  | 591  | 5,532                                                                   | 6,527 | 7,946 | 91,971                                                                   | 126,376 | 179,073 |
| 2078             | 279                                                                     | 401  | 594  | 5,607                                                                   | 6,612 | 8,046 | 92,964                                                                   | 127,601 | 180,582 |
| 2079             | 282                                                                     | 404  | 598  | 5,681                                                                   | 6,698 | 8,146 | 93,958                                                                   | 128,826 | 182,092 |
| 2080             | 284                                                                     | 407  | 601  | 5,756                                                                   | 6,783 | 8,246 | 94,951                                                                   | 130,050 | 183,602 |

## A.6. Additional Figures, Tables, and Results

Figure A.6.1: Net Annual Global Emissions of Methane ( $\text{CH}_4$ ) under the RFF-SPs and the SSPs, 1900-2300

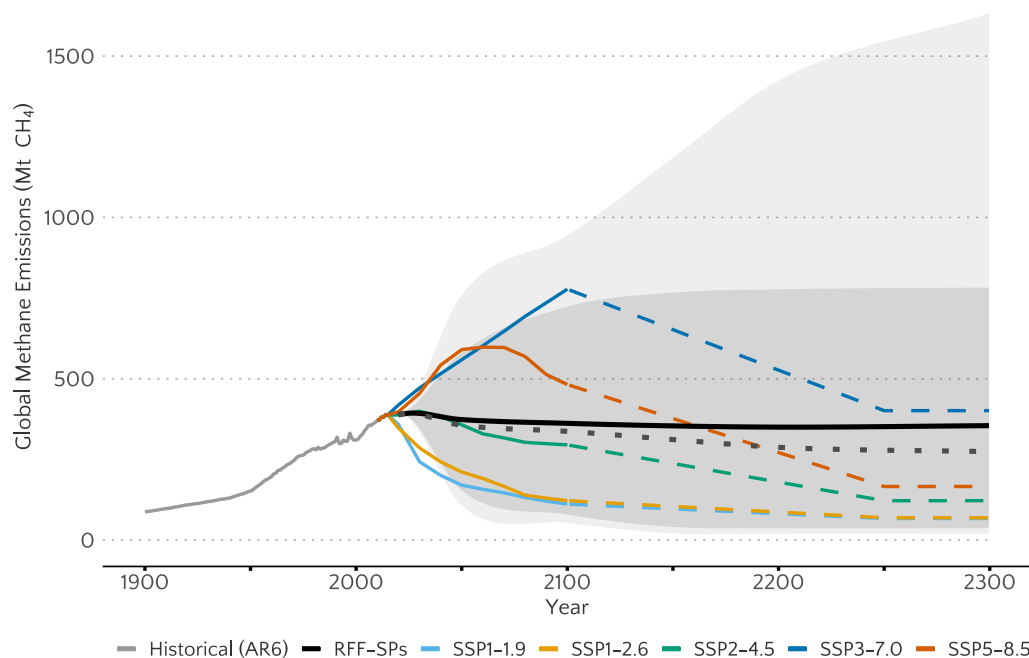
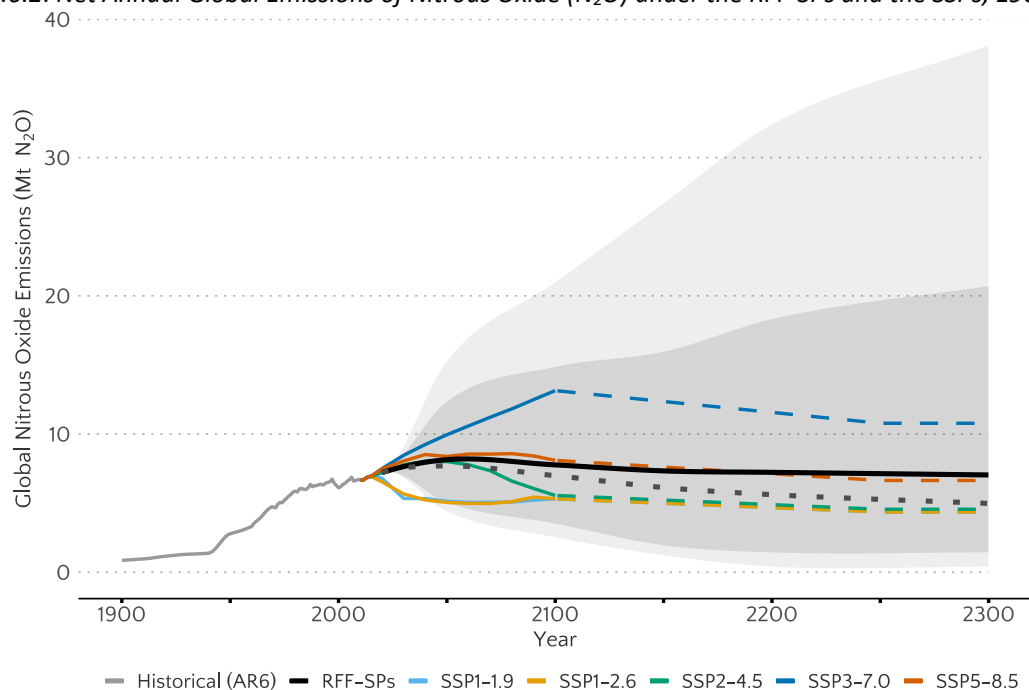


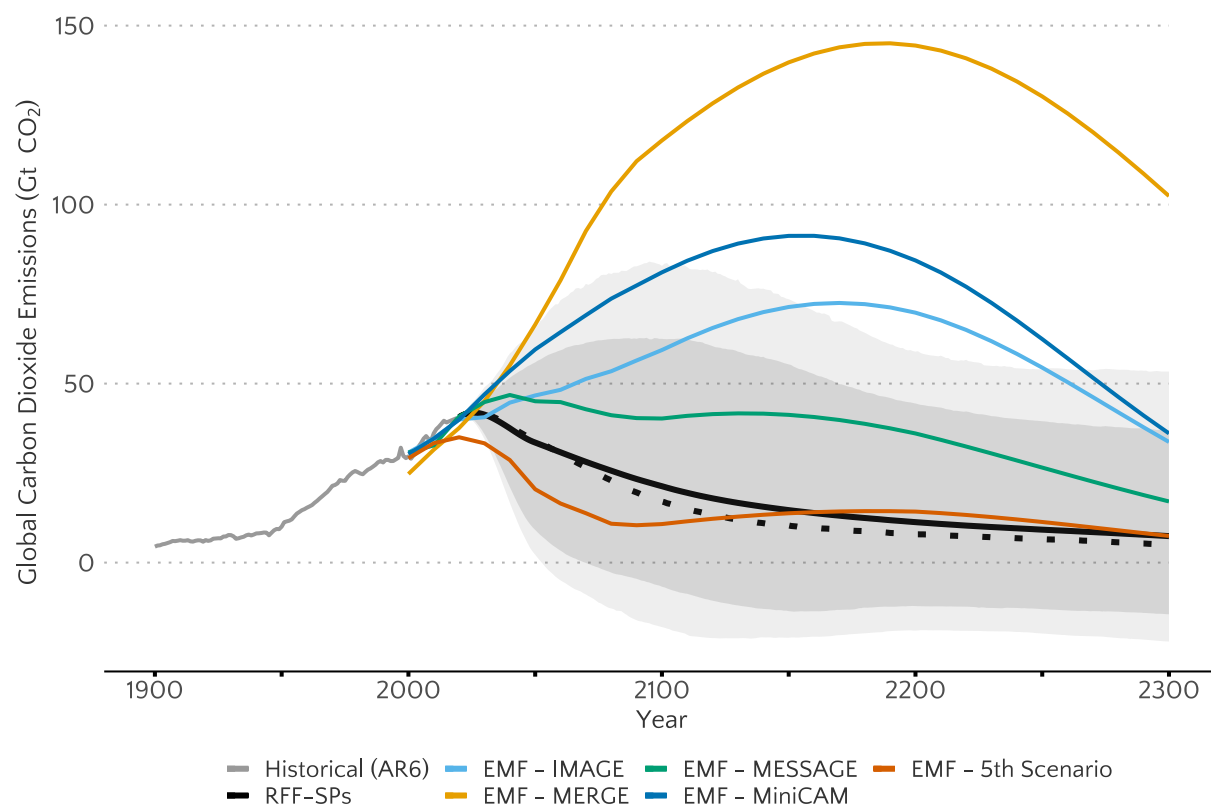
Figure A.6.2: Net Annual Global Emissions of Nitrous Oxide ( $\text{N}_2\text{O}$ ) under the RFF-SPs and the SSPs, 1900-2300



RFF-SP projections based on RFF-SPs (Rennert et al. 2022a). Black lines represent the mean (solid) and median (dotted) projections along with the 5<sup>th</sup> to 95<sup>th</sup> (dark shade) and 1<sup>st</sup> to 99<sup>th</sup> (light shade) percentile ranges. SSP data through 2100 from International Institute for Applied Systems Analysis (IIASA) SSP Database (Riahi et al. 2017). SSPs beyond 2100 (dashed) are based on the commonly used extensions provided by the Reduced Complexity Model Intercomparison Project (Nicholls et al. 2020).



**Figure A.6.3: Net Annual Global Emissions of Carbon Dioxide (CO<sub>2</sub>) under the RFF-SPs and EMF-22 Scenarios, 1900-2300**



*RFF-SP projections based on RFF-SPs (Rennert et al. 2022a). Black lines represent the mean (solid) and median (dotted) projections along with the 5<sup>th</sup> to 95<sup>th</sup> (dark shade) and 1<sup>st</sup> to 99<sup>th</sup> (light shade) percentile ranges. EMF-22 data are drawn from the USG (2010) Stanford Energy Modeling Forum—these are the scenarios underlying the USG (2021) interim estimates.*

Figure A.6.4: Net Annual Global Emissions of Methane ( $\text{CH}_4$ ) under the RFF-SPs and EMF Scenarios, 1900-2300

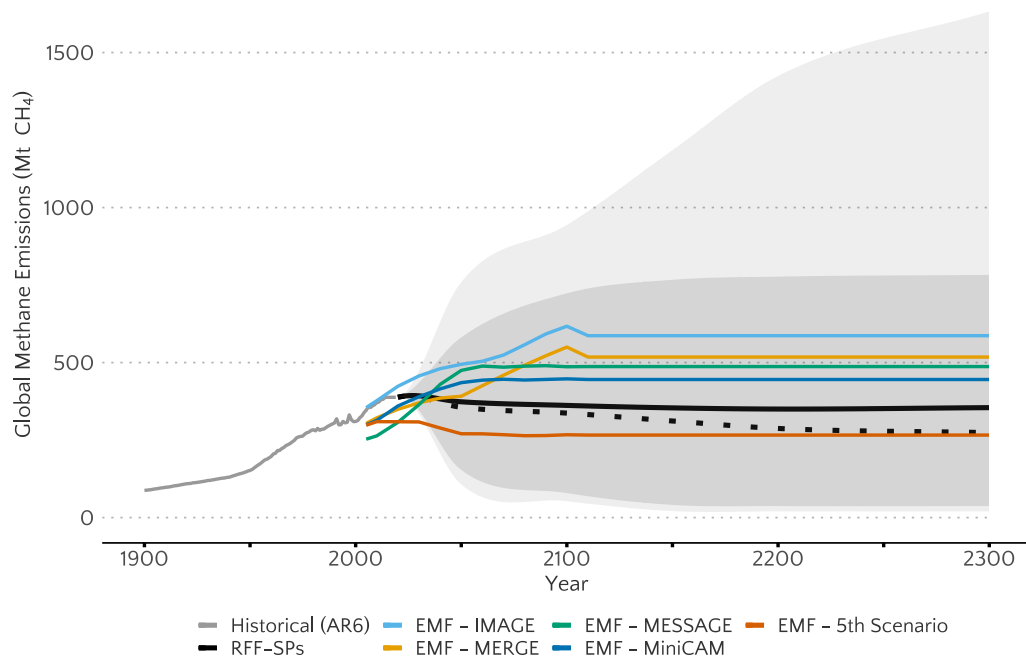
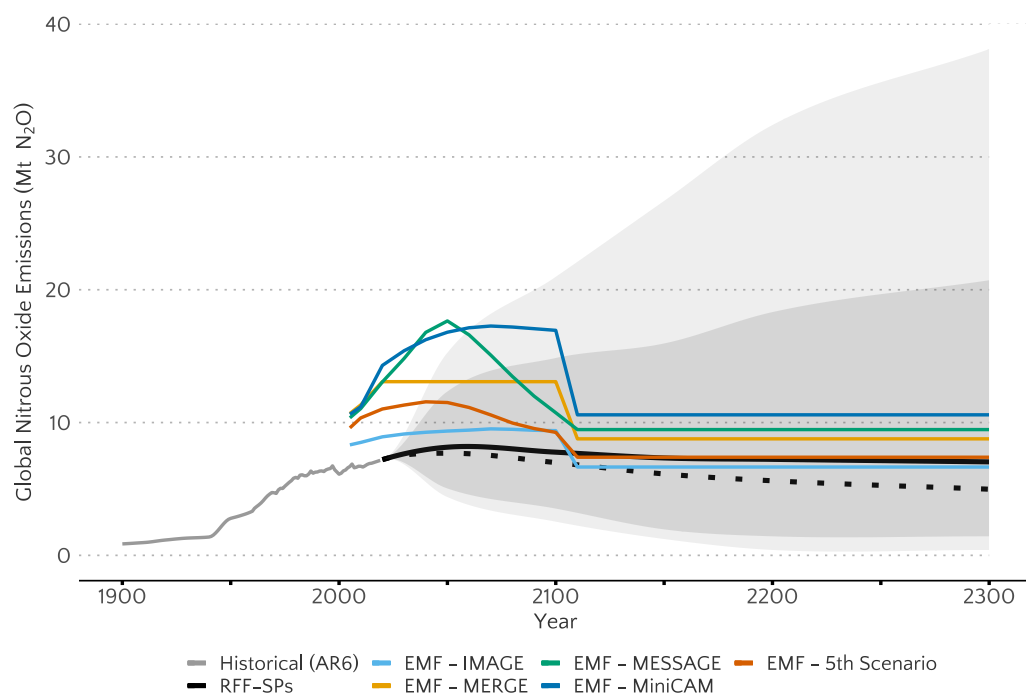


Figure A.6.5: Net Annual Global Emissions of Nitrous Oxide ( $\text{N}_2\text{O}$ ) under the RFF-SPs and EMF Scenarios, 1900-2300



RFF-SP projections based on RFF-SPs (Rennert et al. 2022a). Black lines represent the mean (solid) and median (dotted) projections along with the 5<sup>th</sup> to 95<sup>th</sup> (dark shade) and 1<sup>st</sup> to 99<sup>th</sup> (light shade) percentile ranges. EMF data are drawn from the USG (2010) Stanford Energy Modeling Forum—these are the scenarios underlying the USG (2021) interim estimates.

Figure A.6.6: Global Atmospheric Concentrations of Methane ( $\text{CH}_4$ ), 1900-2300

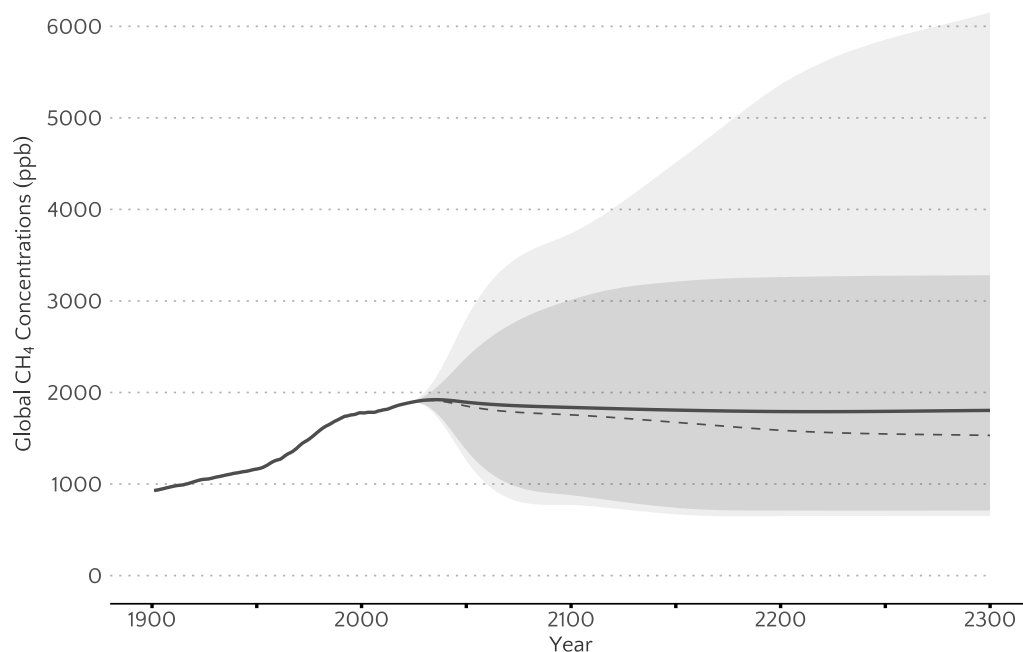
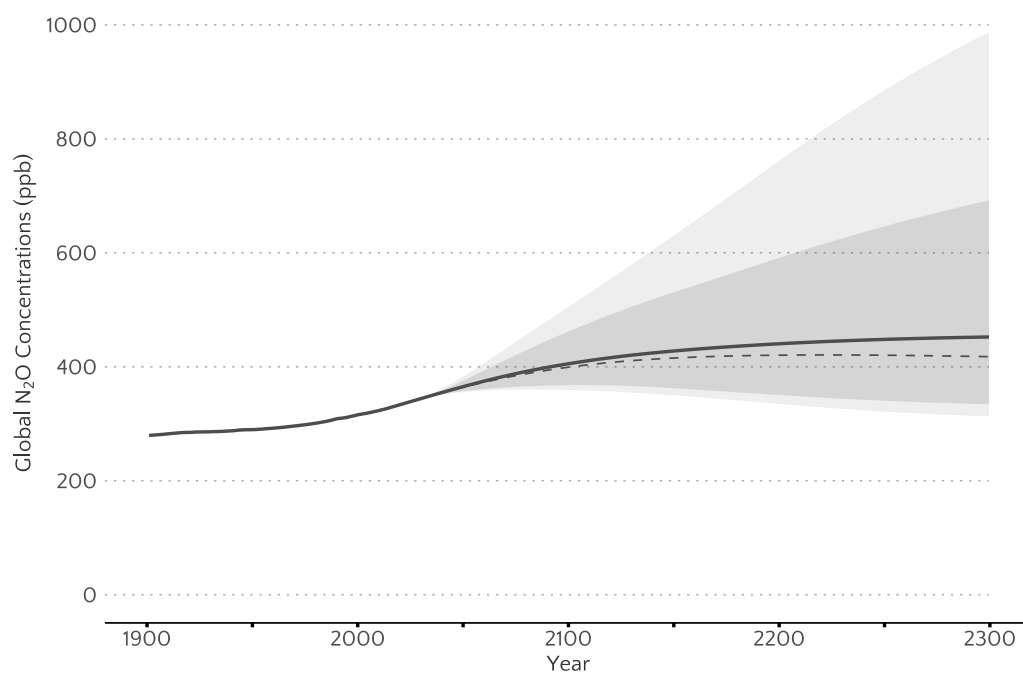


Figure A.6.7: Global Atmospheric Concentrations of Nitrous Oxide ( $\text{N}_2\text{O}$ ), 2020-2300



Historical and future concentrations of methane ( $\text{CH}_4$ , top) and nitrous oxide ( $\text{N}_2\text{O}$ , bottom) are based on the range of emissions from the sampled RFF-SP scenarios used as inputs into FaIR 1.6.2. FaIR 1.6.2 is run with the full, AR6 calibrated (constrained) uncertainty distribution. Therefore, the uncertainty ranges in this figure represent both emissions and physical carbon cycle uncertainty. Mean (solid) and median (dashed) lines along with 5<sup>th</sup> to 95<sup>th</sup> (dark) and 1<sup>st</sup> to 99<sup>th</sup> (light) percentile ranges.

Figure A.6.8: Global Temperature Anomaly from a Pulse of Methane (1MtCH<sub>4</sub>) Emissions, 2020-2300

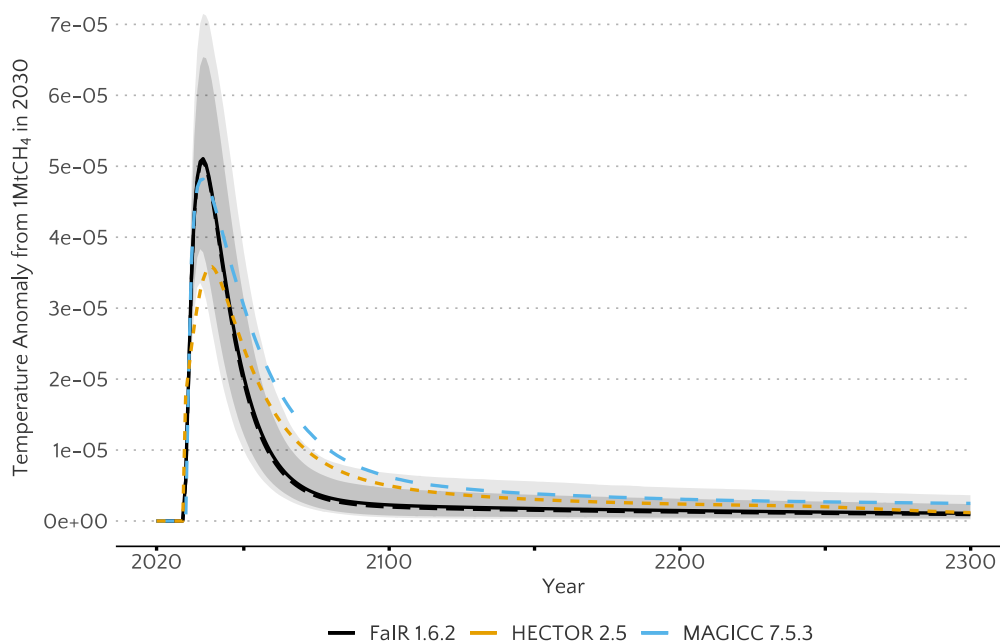
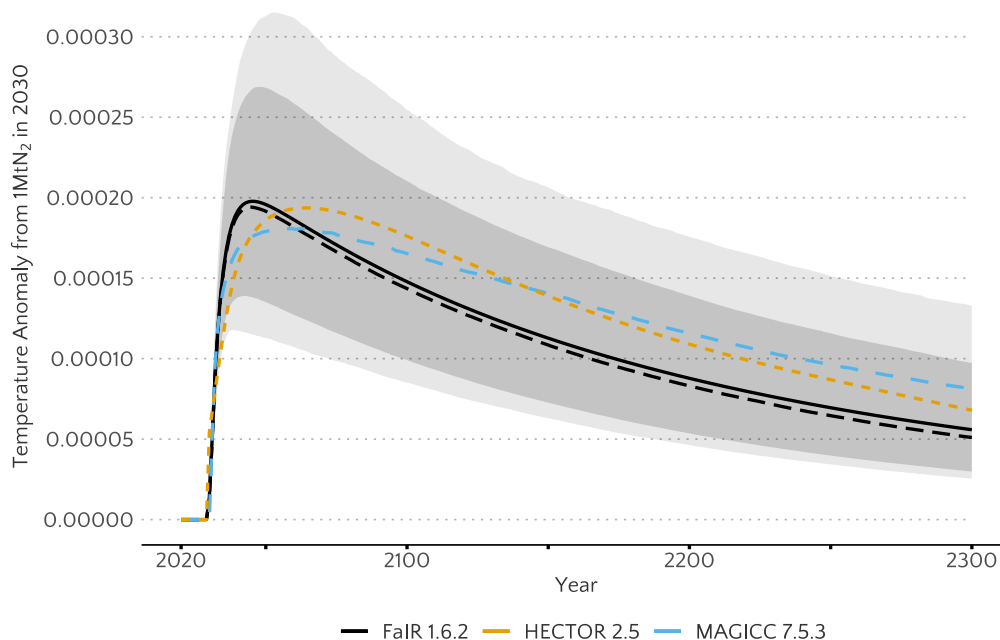
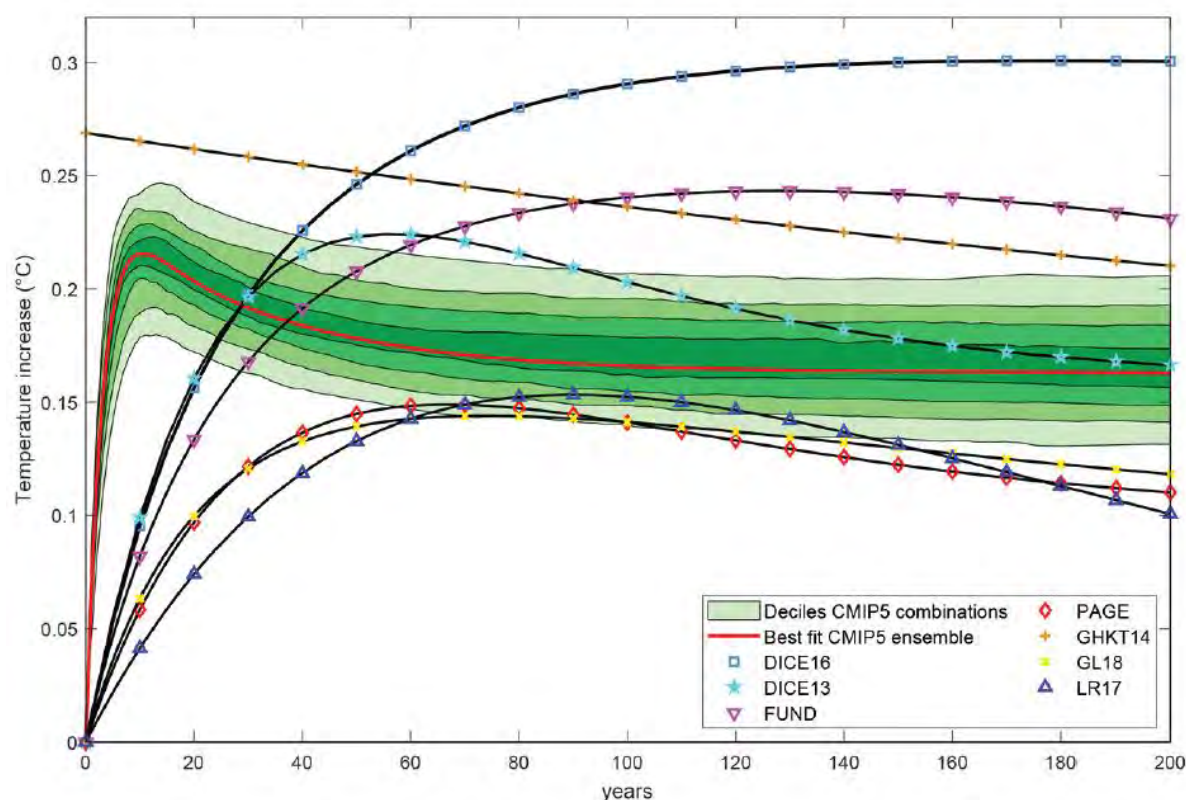


Figure A.6.9: Global Temperature Anomaly from a Pulse of Nitrous Oxide (1MtN<sub>2</sub>) Emissions, 2020-2300



The global temperature response resulting from a pulse of emissions of CH<sub>4</sub> (top) and N<sub>2</sub>O (bottom) in 2030 as projected by FaIR1.6.2, Hector 2.5, and MAGICC 7.5.3. This represents the difference between a reference scenario (using SSP2-RCP4.5 for the figure) and the same scenario including the pulse of emissions. The emission pulse size is 1 GtC for carbon dioxide. Mean (solid) and median (dashed) lines are shown along with the 5<sup>th</sup> to 95<sup>th</sup> (dark shade) and 1<sup>st</sup> to 99<sup>th</sup> (light shade) percentile ranges.

Figure A.6.10: Dynamic temperature response of 256 climate science models (the CMIP5 ensemble) and seven IAMs



Source: Dietz et al. (2021a). The figure displays the dynamic temperature response of 256 climate science models (the CMIP5 ensemble) and seven IAMs to an instantaneous 100 GtC emission impulse against a constant background atmospheric CO2 concentration of 389 ppm. The temperature response of the IAMs is much slower than the climate science models, except Golosov et al. (2014). After 200 years, the temperature response of the IAMs is often well outside the range of the climate science models. The CMIP5 model responses are emulated/fitted by combining the Joos et al. (2013) carbon cycle model and the Geoffroy et al. (2013) warming model.

**Figure A.6.11: Distribution of the Discounted Marginal Damages per Metric Ton of Methane (CH<sub>4</sub>) for 2030 Emissions, by Near-term Ramsey Discount Rate and Damage Module**

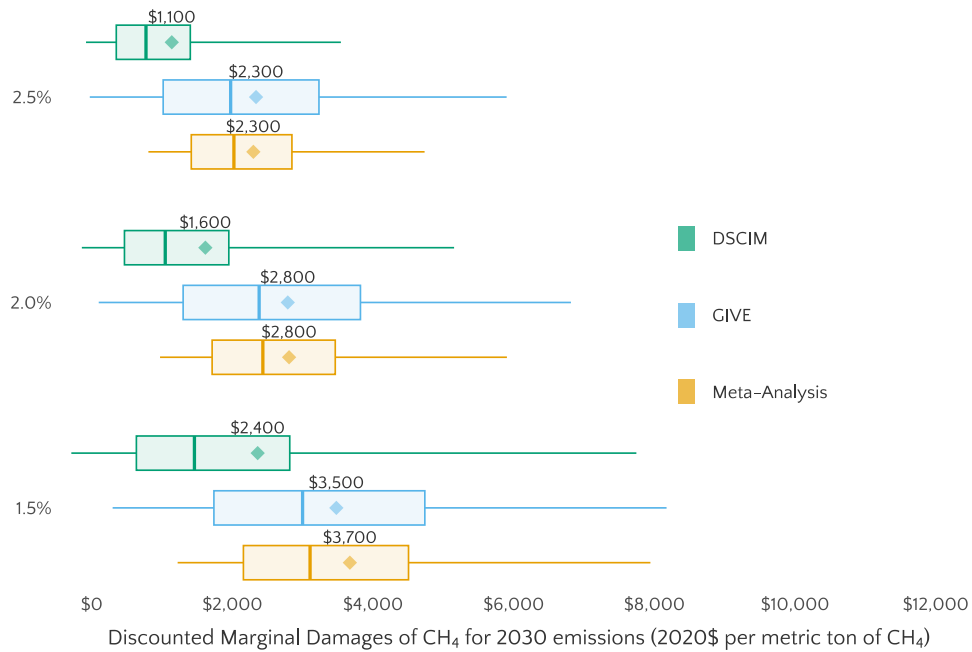
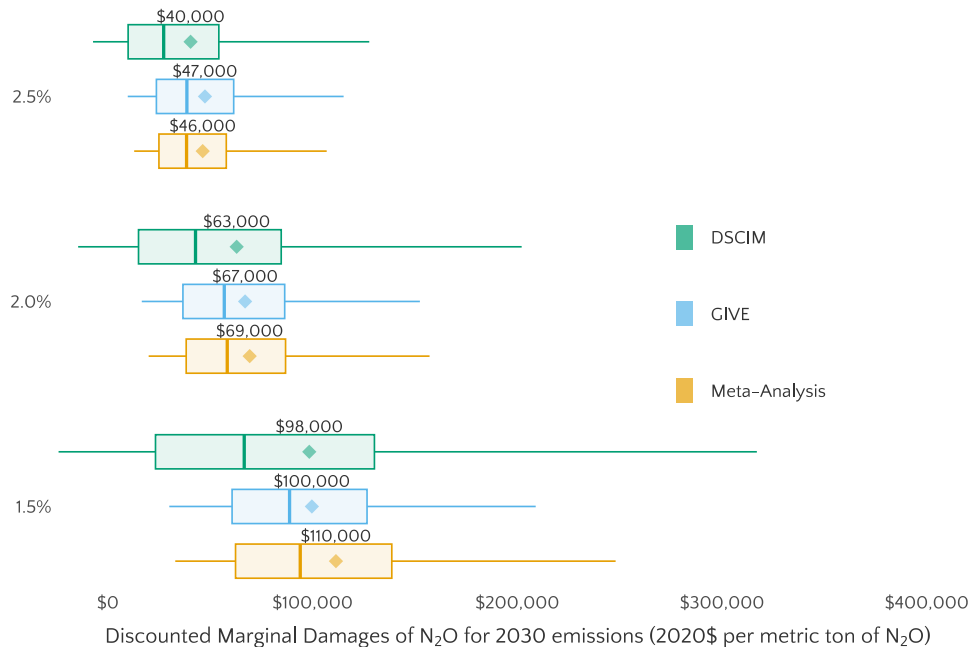


**Figure A.6.12: Distribution of the Discounted Marginal Damages per Metric Ton of Nitrous Oxide (N<sub>2</sub>O) for 2030 Emissions, by Near-term Ramsey Discount Rate and Damage Module**



Boxes span the inner quartile range (25<sup>th</sup> to 75<sup>th</sup> percentiles), whiskers extend to the 5<sup>th</sup> (left) and the 95<sup>th</sup> (right) quantiles. The vertical lines inside of the boxes mark the median of each distribution, and the points inside of the boxes and dollar estimates on top of the boxes mark the simple mean (average).

## **A.7. Valuation Methodologies to Use in Estimating the Social Cost of GHGs**

The EPA will continue to review developments in the literature, including new and robust methodologies for estimating the magnitude of the various direct and indirect damages from climate impacts. EPA will also continue to assess whether there are other parts of this literature or other methodologies to evaluate for potential inclusion in SC-GHG estimation.

Both DSCIM and the GIVE model incorporate sector-specific damage functions published in the peer-reviewed literature. One advantage of the modular approach used by these models is that new or alternative damage functions can be incorporated in a relatively straightforward way, while maintaining the state-of-the-science modules dealing with socioeconomic scenarios, emission trajectories, discounting, and climate modeling used in this report.

As explained in Section 2.3, the damage module component of SC-GHG estimation translates changes in temperature and other physical impacts of climate change into monetized estimates of net economic damages based on the willingness to pay of individuals to avoid those damages. The developers of the damage functions used in this report applied valuation methods that are consistent with the theoretical underpinning of EPA's benefit-cost analysis (BCA) – the Kaldor-Hicks criterion.<sup>172</sup> For example, in DSCIM and GIVE, changes in agricultural output due to climate change are valued using expected market prices for key agricultural commodities. Use of prices to value commodities traded in markets is generally consistent with the Kaldor-Hicks criterion, sometimes called an economic efficiency test. For damage categories that involve non-market impacts (commodities or services not traded in the market, like changes in mortality risks) there is no readily observed price information and there are challenges in capturing the value of something as precious as changes in life expectancy. However, economists have developed a robust literature to infer values for these non-market commodities using methods that are consistent with the economic efficiency test. Because of data limitations and other constraints to performing original research to develop location- and context- specific values to assign to each non-market impact, analysts regularly need to draw upon existing value estimates for use in benefits analysis

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<sup>172</sup> The Pareto criterion maintains that if an economic change does not harm any individual and makes at least one individual better off, there is an increase in social welfare. The Kaldor-Hicks criterion captures the intuition of the Pareto criterion, but allows for the identification of potential improvements in social welfare under conditions where some may be made worse off by the economic change. For a potential increase in social welfare, there needs to be a "potential" Pareto improvement, which occurs when those who gain from the economic change would be willing to fully compensate those made worse off from the economic change. From this criterion, the rules of BCA as an economic efficiency test follow, including the use of the consumer sovereignty principle whereby BCA must value benefits and costs based on individuals' willingness to pay. If the impacts to individuals are measured using a value other than their willingness to pay, the results of the BCA will be unable to identify potential Pareto improvements under the Kaldor-Hick criterion and their interpretation may be unclear. The discipline of the private market to allocate resources cannot work for pollution, so the BCA helps provide this information as one input, amongst many, in the decision-making process. As in a private market, the price in the simulated market test should equal the willingness to pay of individuals on the margin, as any other valuation would cause the test to fail in answering its question. See EPA (2010) for more discussion.

through “benefits transfer.”<sup>173</sup> The benefits transfer methods used by the developers of the DSCIM and GIVE damage functions used in this report are also consistent with the economic efficiency test.

The challenge of valuing climate-related mortality risks provides an illuminating application of these methods. As shown in Section 3.1, net costs of expected premature mortality associated with climate change driven changes in hot- and cold weather comprise the largest share of the DSCIM and GIVE based SC-GHG estimates presented in this report.<sup>174</sup> It is worth noting that valuing premature mortality risks in EPA BCAs is a routine occurrence. Particulate matter, ozone, lead, and many other environmental contaminants can increase mortality risks through various modes of action including, increased cardiovascular disease, cancer, and respiratory disease. To value changes in these mortality risks, EPA uses published research that estimates individuals’ willingness to pay to reduce mortality risks in their own lives – a number that is inaptly termed the “Value of Statistical Life” (VSL)<sup>175</sup> – and then transfers these willingness to pay (WTP) estimates to the risk reductions expected from EPA policy options.<sup>176,177</sup>

EPA’s benefit transfer also recognizes that as per capita income increases, willingness to pay for mortality risk reductions also increases. This parallels the fact that as their income increases individuals are willing to pay more for most goods and services.<sup>178</sup> EPA increases the willingness to pay estimate over time to reflect projected per capita income growth (i.e., by applying a positive income elasticity) as a way to capture that the wealthier we are, the greater our willingness to pay to avoid mortality risks consistent with the empirical evidence. For example, applying an income elasticity of one implies that for every one percent increase in per capita income, the value of mortality risk reductions increases by one percent, such that the willingness to pay for mortality risk reductions remains a constant share of people’s income. EPA’s VSL methodology is peer reviewed by its Science Advisory Board (SAB). EPA periodically engages in a consultation with the SAB on the appropriate range of income elasticities.

In estimating the SC-GHG, the question becomes what VSL to use to monetize expected mortality risk reductions occurring in other countries. Given the small number of high-quality VSL studies in many countries, the vast majority of countries do not have their own official recommended VSL estimates or

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<sup>173</sup> Benefits transfer is the process of applying values estimated in previous studies to a new context. See EPA (2010) for an overview of current EPA guidance on best practices in benefits transfer.

<sup>174</sup> Mortality risk changes are also partially captured in the coastal damage category in each model. See Section 2.3 for more discussion.

<sup>175</sup> As noted by the SAB, “the conventional term used to describe the value of risk reduction (the “value of a statistical life,” or VSL) is easily misinterpreted, leading to confusion about key concepts” (EPA 2011). As explained in OMB Circular A-4 (2003) the “phrase can be misleading because it suggests erroneously that the monetization exercise tries to place a “value” on individual lives”; “... these terms refer to the measurement of willingness to pay for reductions in only small risks of premature death. They have no application to an identifiable individual or to very large reductions in individual risks. They do not suggest that any individual’s life can be expressed in monetary terms. Their sole purpose is to help describe better the likely benefits of a regulatory action” (OMB 2003). Circular A-4 (2023) contains similar guidance (OMB 2023). Put another way, the VSL “represents the rate at which an individual views a change in the money he or she has available for spending as equivalent to a small change in his or her own mortality risk within a specific time period, such as one year” (Robinson et al. 2019b).

<sup>176</sup> For more details on the derivation of EPA’s values for mortality risk reductions, see EPA’s Guidelines for Preparing Economic Analyses (2010), p. 7-8. <https://www.epa.gov/sites/default/files/2017-09/documents/ee-0568-07.pdf>.

<sup>177</sup> A willingness to pay to reduce mortality risk is a ratio, where the numerator reflects the marginal disutility of (usually small) increases in probability of experiencing premature mortality, usually within the next year, and the denominator is the marginal utility associated with additional income/consumption.

<sup>178</sup> In economics, goods for which individuals increase their demand as their income rises, signifying an increased willingness to pay, are called normal goods.



estimates from the empirical literature that can be readily adopted (Robinson et al. 2019a). Therefore, analysts must rely on benefits transfer techniques to develop VSL estimates for other countries that are extrapolated from existing estimates in the U.S. or other countries with robust empirical estimates.

With respect to this report, both the GIVE and DSCIM based damage modules explicitly model changes in the risk of premature mortality due to GHG emissions driven climate change and monetize these climate-related mortality risks consistent with the economic efficiency paradigm. Specifically, as described in Section 2.3, projected changes in premature mortality in the U.S. are monetized using the same value of mortality risk reduction as in the EPA's regulatory analyses (\$4.8 million in 1990 (1990USD)) and adjusted for income growth and inflation following current EPA guidelines and practice (EPA 2010) and consistent with SAB advice (see e.g., EPA 2011, OMB 2003), resulting in a 2020 value of \$10.05 million (2020USD). Valuation of mortality risk changes outside the U.S. is based on an extrapolation of the EPA value that equalizes willingness-to-pay as a percentage of per capita income across all countries (i.e., using an assumed income elasticity of 1). The use of a benefits transfer approach based on a positive income elasticity is consistent with the approach used in the default version of the damage functions and published studies used in this report (e.g., Rennert et al. 2022b, Carleton et al. 2022, and Diaz 2016), other academic literature (e.g., Hasegawa et al. 2016, Springmann et al. 2016, Sarofim et al. 2017, Markandya et al. 2018, and the Lancet Commission on pollution and health (Landrigan et al. 2018)), advice given to the IWG by experts at the 2011 U.S. EPA and U.S. DOE Workshop on Improving the Assessment and Valuation of Climate Change Impacts for Policy and Regulatory Analysis (ICF International 2011), and other prominent domestic and international guidance documents that speak to international mortality risk reduction valuation. See, for example, the 2019 Gates Foundation Reference Case Guidelines for Benefit-Cost Analysis in Global Health and Development Guidelines (Robinson et al. 2019a) and literature cited therein (e.g., Robinson et al. 2018, 2019b, OECD 2016, World Bank and IHME 2016, Viscusi and Masterman 2017a, 2017b, Masterman and Viscusi 2018), and the U.S. Millennium Challenge Corporation guidance for conducting benefit-cost analysis (MCC 2021). Many international organizations also regularly use country-level measures of the willingness-to-pay for mortality risk reductions based on a positive income elasticity in cross country analyses (see, for example, Tan-Soo 2021, Roy and Braathen 2017, Roy 2016, Laxminarayan et al. 2007).

Given that the methodology in this report is grounded in a willingness to pay concept and the empirical evidence shows a positive relationship between income and the willingness to pay for mortality risk reductions, the willingness to pay for mortality risk reductions in countries with lower average incomes is less than the willingness to pay for mortality risk reductions in higher income countries. It is important to stress that this metric does not reflect the "value" that this approach places on mortality risks in different parts of the world. Rather, it reflects an estimate of the willingness to pay for mortality risk reductions by the average resident of countries or regions conditional on their income. EPA's Science Advisory Board, while reviewing our methodology to assign monetized estimates to mortality risk reductions also recognized this challenge:

"While it is clear from economic theory that individual WTP may vary with individual and risk characteristics, the SAB acknowledges that the objectives, methods, and principles underlying benefit cost analysis and particularly the values of mortality risk reductions and other non-market goods are often misunderstood or rejected as inappropriate by many participants and commentators on the policymaking process. In the past, for example, the Agency was criticized for considering VRRs [VSL] that differ by

individuals' age. However, as acknowledged in the White Paper, values for health risk reductions are not "one size fits all." Applying a willingness to pay value to a targeted population (such as low income or elderly) that exceeds that group's willingness to pay for reduced risk could result in decisions that ultimately reduce the well-being of the targeted group. The proposed change of terminology and application of VRRs [VSL] that differ with individual and risk characteristics provide an opportunity for constructive engagement with the public and other interested parties concerning these topics."<sup>179</sup> (EPA 2011).

It is important to note that EPA's BCAs, based on the economic efficiency criterion, is one of several economic analyses done to inform decision making and the public. Notably, distributional considerations are also paramount. In general, when a BCA is undertaken, EPA also conducts an environmental justice analysis, examining the incidence of environmental impacts both in the baseline and those that would result from the policy options under review.<sup>180</sup> This is in addition to economic impact analyses that are conducted by EPA to examine how different populations are affected by other expected outcomes of the policy options.

There is also a separate literature that argues that equity and other concerns should be addressed directly throughout all elements of a BCA (e.g., Scitovsky 1951, Lutz 1995, Farrow 1998, Persky 2001, Little 2002). This issue comes up in regard to climate change, since the impacts of climate change are not manifesting uniformly across space and populations, as highlighted in Section 3.2, with some of the most vulnerable populations living in locations that will experience some of the most severe effects. These facets of climate change have led some analysts (e.g., Azar and Sterner 1996; Fankhauser et al. 1997; Azar 1999; Anthoff et al. 2009; Anthoff and Tol 2010; Dennig et al. 2015, Anthoff and Emmerling 2019) to employ "equity weighting" to incorporate distributional equity objectives into estimates of the SC-GHG. As noted by Anthoff and Emmerling (2019), "[e]xisting equity weighting studies assume a social welfare function (SWF) that exhibits inequality aversion over per capita consumption levels." As defined by EPA's SAB "[a] social welfare function essentially involves two stages. In the first stage, each group has its own definition of welfare, which is impacted by the various effects set out in this chapter. In the second stage, the groups are weighted to account for distributional concerns" (EPA 2021f). The argument for equity weighting in

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<sup>179</sup> In that same review, the SAB opined more specifically on whether EPA should use a country-wide average VSL or more granular VSL estimates. While this SAB review was addressing how mortality risks for domestic EPA regulations should be valued, the insight is easily extended to how the mortality risks in other countries are valued in this report. "Recognizing that VRR [VSL] is a metric that can vary with both individual and risk characteristics, the conceptually appropriate method to estimate the benefits to the U.S. population of a change in mortality risk that results from environmental policy is to estimate the risk changes faced by each individual over time, value these changes using the appropriate individual VRRs [VSLs], and sum the results over the population. In contrast, an alternative "short-cut" approach is conventionally applied. The short-cut approach is to multiply the number of people in the population by the population-mean risk reduction (yielding the number of "lives saved") and multiply that by the population-mean VRR [VSL]. The short-cut approach yields an approximation to the conceptually appropriate method. It requires information on only the average VRR [VSL] and risk reduction, not on how VRR [VSL] and risk reduction vary across individuals. The approximation is exact when any of three conditions hold: (a) all individuals face the same risk reduction; (b) all individuals have the same VRR; or (c) individual risk reductions and VRRs [VSLs] are uncorrelated in the population. If none of these conditions holds, the short-cut approach introduces bias as a result of "premature aggregation" (Cameron 2010, Hammitt and Treich 2007)" EPA (2011).

<sup>180</sup> EPA has detailed technical guidance on conducting environmental justice analyses (EPA, 2016c).

this strand of literature is “that a given (say one dollar) cost which affects a poor person (in a poor country) should be valued as a higher welfare cost than an equivalent cost affecting an average [high income country] citizen” to reflect a decreasing marginal utility of income (Azar and Sterner 1996). The degree to which the valuations differ across those individuals will, in part, be dependent upon the degree of society’s intra-temporal inequality aversion specified within the SWF.

In place of directly incorporating distributional equity objectives through the specification of a SWF, a couple of studies have explored the impact of alternative VSL assumptions within the analysis of mortality impacts of climate change. Bressler (2021), in an effort to reflect distributional concerns, considered the use of a constant VSL across all countries in place of an income adjusted VSL designed to reflect willingness to pay. This approach weights the value of mortality risk changes to residents of lower income countries such that it is higher than their willingness to pay and weights mortality risk changes to higher income countries such that they are valued less than their willingness to pay. Carleton et al. (2022) included an empirical exploration in sensitivity analyses of how climate-related mortality damages change under a variety of valuations. They found net damages from climate change mortality risk changes of \$15-\$65 per ton CO<sub>2</sub> when using a WTP-based VSL (similar to the approach used in this report) and damages of \$46-\$144 per ton CO<sub>2</sub> when using a global average VSL, where the range is across the socioeconomic-emissions scenario modeled.<sup>181</sup>

While EPA will continue to assess the broader literature on BCA, social welfare, and equity as it seeks to apply the best available science in its analyses, this report develops SC-GHG estimates that are considered to be generally consistent with the Kaldor-Hicks criterion that guides all the other elements of the EPA’s BCAs.<sup>182</sup> In addition, this approach is consistent with the benefits transfer approaches used in the default versions of the damage functions and published studies used in this report. This approach also ensures that U.S. mortality risks from climate impacts are valued consistently with how EPA values U.S. mortality risks from other causes. In addition to conducting a Kaldor-Hicks based BCA, EPA has and will continue to conduct detailed analyses of environmental justice concerns of climate change in its rulemakings as required and appropriate (for example, EPA 2021c) and the distributional outcomes of climate change in detailed quantitative analyses,<sup>183</sup> so as to ensure that decision-makers and the public have robust information as to the damages of climate change and their distributional effects.

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<sup>181</sup> These values were calculated using a constant 2% discount rate and only reflect damages from net changes in mortality risks from climate change using different scenarios and climate modeling than was applied in this report.

<sup>182</sup> The VSL for other countries is estimated using PPP-adjusted GDP. One can use either the market exchange rate or PPP to adjust the GDP value, but it involves a tradeoff between consistency with the potential compensation test of the Kaldor-Hicks criterion and improved representation of the preferences in the country under consideration. Using the PPP takes into account the different price levels and different baskets of goods consumed across countries, and it more accurately describes relative standards of living across countries. This is a standard approach in the literature (Hammit and Robinson 2011, Nordhaus 2017, 2018a, Robinson, et al. 2019a) and is the same approach used in the damage function estimates in GIVE and DSCIM. This is currently the best practice for benefit transfer of VSL estimates, but we recognize that this is an approximation.

<sup>183</sup> For example, 2021 Climate Change and Social Vulnerability report (EPA 2021e).

## A.8. Treatment of Uncertainty

The methodologies in this report incorporate many major advances in the treatment of uncertainty in integrated assessment modeling. Table A.8.1 summarizes the quantified sources of uncertainty in the SC-GHG estimates presented in this report. The left column lists the inputs and components of each module that contribute to uncertainty. The right columns briefly describe the key modeled uncertainties and their sources. There are other dimensions of uncertainty that are addressed in preliminary steps of the models' estimation and/or the development of the underlying studies used in the models that are not enumerated in the table. For specific details of each model's methodology, see Section 2. See Section 3.2 for discussion of sources of uncertainty that have not yet been quantified and are thus not reflected in this report's estimates.

*Table A.8.1: Treatment of Uncertainty*

| Model Component                                                                        | Key Modeled Uncertainties                                                                                                                                                                                                                                                            | Uncertainty Source                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|----------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Socioeconomics and emissions module (RFF-SPs)</b>                                   |                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Global CO <sub>2</sub> , CH <sub>4</sub> , and N <sub>2</sub> O emissions trajectories | Reflect uncertainty in fossil fuel and process-related CO <sub>2</sub> , CH <sub>4</sub> , and N <sub>2</sub> O emissions, natural CO <sub>2</sub> stocks and negative-emissions technologies, future mitigation policy, sensitivity of emissions to future economic growth.         | Quantiles (minimum, 5 <sup>th</sup> , 50 <sup>th</sup> , 95 <sup>th</sup> , maximum, additional percentiles) based on expert elicitation for five benchmark years: 2050, 2100, 2150, 2200, and 2300 and five GDP per capita trajectories (Rennert et al. 2022a).                                                                                                                                                                                           |
| Country-level GDP growth rates                                                         | Common global economic growth factor, group-of-countries-specific factors, group-of-groups-specific factors, and country-specific growth factors.<br><br>Parameters accounting for speed of convergence, convergence groups (i.e., clubs) and persistence also treated as uncertain. | Uncertainty distributions estimated using a Bayesian model and historical data for 113 countries over 118 years (Muller et al. 2022).<br><br>Statistical results are combined with performance-weighted results of expert elicitation, with increasing weight given to expert elicitation over time. Experts provided quantiles (1st, 5th, 50th, 95th, and 99 <sup>th</sup> ) for four benchmark years: 2050, 2100, 2200, and 2300 (Rennert et al. 2022a). |
| Country-level population                                                               | Total fertility rate (TFR), life expectancy, and net migration rate.                                                                                                                                                                                                                 | Uncertainty in TFR and life expectancy based on statistical model used by UN for population forecasting (UN 2015); Long term TFR distribution adjusted based on expert elicitation (Raftery and Ševčíková 2023).<br><br>Uncertainty in net migration rates based on age-adjusted net migration forecasting approach (Azose, Sevcikova, and Raftery 2016), as described in (Raftery and Ševčíková 2023).                                                    |
| <b>Climate module</b>                                                                  |                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Global mean surface temperature                                                        | Effective heat capacities of the surface and deep ocean layers, deep ocean heat uptake efficacy, the                                                                                                                                                                                 | Sampled from a calibrated 2,237-member ensemble of parameters that was                                                                                                                                                                                                                                                                                                                                                                                     |

|                                  |                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|----------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                  | integrated airborne fraction of CO <sub>2</sub> over the pre-industrial period, the strength of different forcing agents, a climate feedback term, and other key model parameters. <sup>184</sup>                                                                                                  | produced using FaIR as part of the IPCC AR6 (IPCC 2021a,b).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| FACTS sea level model            | Numerous parameters related to thermal expansion, ice sheets, and other key model parameters. <sup>185</sup>                                                                                                                                                                                       | Parameterizations based on the two approaches that the IPCC AR6 characterized as “medium confidence”, assuming those two approaches were equally likely (IPCC 2021c, Garner et al. 2021); excludes possible contributions from marine ice cliff instability (MICI) and ocean forcing on basal melt rates (CIL 2023).<br><br>Additional SLR resulting from the emissions pulse is estimated using the “semi-empirical” sea level model (Kopp et al. 2016) calibrated based on historical data; probabilistic draws of GMST are quantile-mapped to the probabilistic draws of the FACTS projections (CIL 2023). |
| BRICK sea level model            | Numerous parameters related to thermal expansion, Greenland and Antarctic ice sheets, glaciers and small ice caps, land water storage, and other key model parameters. <sup>186</sup>                                                                                                              | Sampled a 10,000-member ensemble of parameters derived from a Bayesian calibration framework; parameterization assumptions are consistent with IPCC AR6 projections that include MICI (Rennert et al. 2022b).                                                                                                                                                                                                                                                                                                                                                                                                 |
| <b>Damages module</b>            |                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <b><i>DSCIM</i></b>              |                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Heat- and cold-related mortality | Dose-response functions for each damage category are estimated at the impact-region level. Specifications vary by impact category but generally include parameters on measures of regional temperature, precipitation, and income. <sup>187</sup> The energy dose-response function varies by fuel | Dose-response parameters are sampled in Monte Carlo draws from their joint probability distribution.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Energy expenditures              |                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Agriculture                      |                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Labor productivity               |                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

<sup>184</sup> A more detailed list of uncertain parameters and their quantile values for the FAIR v1.6.2 climate model is available in Supplementary Information Table 3 in Rennert et al. (2022b).

<sup>185</sup> See CIL (2023) for more details. A more detailed description of the IPCC AR6 SLR projections and methodology (IPCC 2021c, Garner et al. 2021) is available at: [https://sealevel.nasa.gov/data\\_tools/17](https://sealevel.nasa.gov/data_tools/17).

<sup>186</sup> A more detailed list of uncertain parameters and their quantile values for the BRICK sea level model is available in Supplementary Information Table 4 in Rennert et al. (2022b).

<sup>187</sup> For DSCIM mortality, energy, agriculture, and labor dose-response details, respectively see Carleton et al. (2022) Section IV; Rode et al. (2021) Methods: Econometric estimation of energy-temperature responses; Hultgren et al. (2022) Methods section; and Rode et al. (2022) Section 4.

|                                   |                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                 |
|-----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                   | category; the agriculture dose-response function varies by crop; and the labor dose-response function varies by high- and low-risk groups (based on workers' weather exposure).                                                                   |                                                                                                                                                                                                                                 |
| <b>GIVE</b>                       |                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                 |
| Heat- and cold- related mortality | Regional damage function coefficients                                                                                                                                                                                                             | Sampled from normal distributions centered on the regional point estimate and set the standard deviation equal to the reported standard error in Cromar et al. (2022).                                                          |
| Agriculture                       | Regional damage function coefficients                                                                                                                                                                                                             | Sampled from triangular distributions of low, central, high damage function parameterizations in Moore et al. (2017), while preserving covariance between regions arising through connections in the global trade network.      |
| <b>Meta-Analysis</b>              | Parametric uncertainty in the meta-analysis damage function estimation                                                                                                                                                                            | Monte Carlo estimation sampled from the distribution of damage function parameters.                                                                                                                                             |
| <b>Discounting module</b>         | <p>Uncertainty in components of Ramsey discounting rate, including socioeconomics (economic growth and population) and the correlation of economic growth and climate damages.</p> <p>Sensitivity analysis on near-term target discount rate.</p> | <p>Calibration relies on the probabilistic socioeconomics described above (Newell et al. 2022, Rennert et al. 2022b).</p> <p>Range of three near-term target rates based on review of empirical evidence on interest rates.</p> |

# **Michigan Council on Climate Solutions: Energy Production, Transmission, Distribution, and Storage Workgroup Recommendations**

**October 2021**

**Co-chairs:**

Douglas Jester, 5 Lakes Energy

Commissioner Katherine Peretick, Michigan Public Service  
Commission

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Governor Whitmer’s Executive Directive on climate (ED 2020-182<sup>1</sup>) along with (ED 2020-10<sup>2</sup>) establishes the structure of the Council on Climate Solutions (“Council”), tasked with acting in an advisory capacity to the governor and EGLE in formulating and overseeing the implementation of the MI Healthy Climate Plan, which will serve as the action plan for Michigan to reduce GHG emissions 28% below the 2005 levels by 2025, achieve economy-wide carbon neutrality by 2050, and net negative GHG emissions thereafter. In order to work towards developing these goals, it is important to understand Michigan’s baseline GHG levels. The following chart shows Michigan emissions level per energy sector, comparing 2005 to 2018 (the most recent complete data set by the U.S. Energy Information Administration).<sup>3</sup>

| Michigan Carbon Emissions<br>2005 (million metric tons) | Residential<br>Sector | Commercial<br>Sector | Industrial<br>Sector | Transportation<br>Sector | Electric Power<br>Sector | All Sectors |
|---------------------------------------------------------|-----------------------|----------------------|----------------------|--------------------------|--------------------------|-------------|
| Coal                                                    | 0.0                   | 0.3                  | 7.3                  | 0.0                      | 67.8                     | 75.4        |
| Petroleum Products                                      | 4.6                   | 0.9                  | 5.8                  | 53.8                     | 0.8                      | 65.9        |
| Natural Gas                                             | 19.3                  | 9.4                  | 12.0                 | 1.5                      | 7.0                      | 49.2        |
| Total                                                   | 23.9                  | 10.6                 | 25.1                 | 55.3                     | 75.6                     | 190.5       |
|                                                         |                       |                      |                      |                          |                          |             |
| Michigan Carbon Emissions<br>2018 (million metric tons) | Residential<br>Sector | Commercial<br>Sector | Industrial<br>Sector | Transportation<br>Sector | Electric Power<br>Sector | All Sectors |
| Coal                                                    | 0.0                   | 0.0                  | 5.0                  | 0.0                      | 43.2                     | 48.2        |
| Petroleum Products                                      | 2.8                   | 1.5                  | 4.0                  | 52.3                     | 1.6                      | 62.3        |
| Natural Gas                                             | 18.2                  | 10.0                 | 10.1                 | 1.2                      | 14.1                     | 53.6        |
| Total                                                   | 21.0                  | 11.5                 | 19.2                 | 53.5                     | 58.9                     | 164.1       |

As Figure 1 shows, carbon dioxide emissions have decreased from 2005 to 2018, including a significant decrease in emissions from electric power generation. Meanwhile, on-site natural gas combustion continues to be the primary source of emissions from the residential, commercial, and industrial sectors. As described below, the Energy Production, Transmission, Distribution, and Storage (“EPTDS”) Workgroup scope covered both the electric power system and the natural gas system, giving it broad responsibility for identifying actions to reduce emissions from multiple sectors.

<sup>3</sup> State Energy Profile Data (eia.gov)

## PROCESS OVERVIEW

Over the past six months, the EPTDS Workgroup hosted a series of 13 stakeholder meetings engaging with approximately 150 stakeholders in total, averaging 87 stakeholders per meeting. Our workgroup heard from experts across the industry including 29 external speakers, coordinated subgroup discussions, and incorporated feedback towards the development of these recommendations. This Workgroup primarily focused on analyzing decarbonization of the power sector, consisting of the electricity and natural gas industry in Michigan, with a lesser focus on end-uses and did not discuss extraction issues around oil and petroleum, nor transportation fuels, understanding those were better dealt with in other Council on Climate Solutions Workgroups.

The co-chairs of the EPTDS Workgroup were Douglas Jester, Managing Partner of 5 Lakes Energy and Katherine Peretick, Commissioner on the Michigan Public Service Commission (MPSC). The planning team included Jill Rusnak and Sarah Mullkoff of the MPSC, and Trevor Drake of the Great Plains Institute.

The process framework for the EPTDS Workgroup consisted of three phases:

- Phase One included presentations by major stakeholders and external experts to build the group's understanding of the current state of the energy system in Michigan and opportunities and challenges for reducing emissions;
- Phase Two divided the stakeholders into eight subgroups, each with a unique focus area, to develop and deliberate recommendations informed by the previous meetings as well as by a stakeholder survey;
- Phase Three provided an opportunity to review the subgroup recommendations, resolve differences, and package the list of consolidated recommendations for presentation to the Council on Climate Solutions.

Across all phases, stakeholders were invited to provide feedback in written form, live, and through survey responses, which were incorporated into the final recommendations.

## RECOMMENDATION DEVELOPMENT

During Phase Two, the Workgroup broke up into eight subgroups to develop draft recommendations in response to the following topics, assumptions, and questions that were developed by the co-chairs. These topics were shaped by the interest indicated in a stakeholder survey following the Phase One level-setting presentations, which collected stakeholders' interest and expertise in a variety of topics within the broad framework of energy production, transmission, distribution, and storage. The eight subgroups established for the generation of recommendations were as follows:

- **Electric IRP Guidelines:** In order to achieve economy-wide net zero emission by 2050 and necessary interim targets, what integrated resource planning guidelines for electric utilities should be adopted by the MPSC? This should include transmission planning as well as traditional resource planning.

- **Siting Renewables and Storage – Utility Scale:** Based on current and authoritatively projected costs, a very low carbon power system will include very high penetration of renewable generation and significant energy storage. Where should this renewable generation be located and what policies are needed to site sufficient renewables? Where should energy storage be located, both geographically and within the grid? This workgroup will address the relative roles of behind-the-meter resources, distributed front-of-meter resources, and large centralized resources as well as urban and rural location and underlying land uses.
- **Siting Renewables and Storage – Distributed Generation Scale** (same framing as previous).
- **Demand Flexibility, Distributed Energy Resources (DERs)s, and Grid Modernization:** Based on current and authoritatively projected costs, a very low carbon power system will include very high penetration of renewable generation. Such a power system will require new approaches to achieving load balance while reliably meeting customer needs for energy services. What are the roles of demand scheduling and of flexible demand, distributed generation, vehicle to grid, residential energy storage, microgrids, and other grid modernization methods, and what policies should be followed to better align demand and supply?
- **Transmission and Storage Load Balancing:** Based on current and authoritatively projected costs, a very low carbon power system will include very high penetration of renewable generation. Such a power system will require new approaches to achieving load balance while reliably meeting customer needs for energy services. What are the roles for transmission, seasonal storage, and distributed storage? What policy and regulation changes are required to enable this?
- **Preparing for and Advancing Electrification:** Assume that electrification of both transportation and heating is necessary to achieve economy-wide net zero GHG emissions. What electric utility actions are necessary or desirable to accommodate the resulting electricity use and to encourage electrification? What changes are required by transmission owners and operators? What changes need to be implemented by the energy markets (MISO and PJM)?
- **Natural Gas – Decarbonized Gaseous Fuels:** Assume that gas utilities will continue to function largely as they do, but that energy efficiency, renewable natural gas, hydrogen, etc. will be maximally used to minimize GHG emissions from users of natural gas. How much reduction in GHG emissions can we expect and through what combination of policies? What policies should be pursued to reduce methane emissions and leaks from any and all sources?
- **Natural Gas – Winding Down the Gas System:** Assume that sufficient GHG emissions reductions will require substantial electrification of building heating. By what strategies and policies could we reduce or even eliminate the gas distribution system? What policies should be followed to deal with stranded costs?

These eight subgroups met at least on a bi-weekly basis, some more often, to develop GHG reduction recommendations within their individual framing. Importantly, while the subgroups were asked to develop recommendations, they were not asked to achieve consensus on the recommendations.

These eight subgroups ultimately developed a total of 73 independent recommendations. Of those, the co-chairs and planning team combined and identified key themes among these independent recommendations, grouping them together under five overarching recommendations, which are discussed further in subsequent pages of this document:

1. Implement holistic and integrated energy system planning
2. Enable behind-the-meter resources
3. Explore innovative rate designs
4. Facilitate siting of necessary energy infrastructure
5. Evaluate gas system regulatory and policy options

## Context for the Recommendations

As noted above, this workgroup was tasked with exploring recommendations for decarbonizing not only electricity supply, but also natural gas supplied to buildings and industry. On the gas side, there was a common assumption that to achieve significant greenhouse gas reductions, one or both of the following would need to become true: the gas system would need to be shrunk in favor of electrification, and/or the gas being delivered through the system would need to switch to forms of net zero emissions gaseous fuels. As described above, the workgroup considered both of these pathways. The recommendations below reflect how we can appropriately handle the transition and substantial changes that come with decarbonization of natural gas usage.

On the electric side, the Workgroup's recommendations primarily look toward regulatory and policy mechanisms that encourage utilities to decarbonize as opposed to focusing on end-users' options, which will be covered in-depth in the Buildings and Housing, Energy Intensive Industries, and the Transportation Workgroups. The recommendations from our EPTDS Workgroup largely promote a swift transition to electrification, which also requires a thoughtful transition that is considerate of societal impacts and a holistic perspective on long-range planning. For both natural gas and electricity planning, it was also understood that Michigan's utilities must maintain the fundamental function and obligation to serve customers and preserve reliability standards during an environment of ever-changing and increased severe climate-induced weather events.

It is important to note that while several of the proposed solutions point toward direct actions that the Michigan Public Service Commission (MPSC) should take, neither the co-chairs, planning team, nor the MPSC necessarily endorse all of these concepts. Rather, this Workgroup merely presents the recommendations as an output of the stakeholder effort. The co-chairs of this workgroup viewed their job as facilitators of a stakeholder process, rather than authors of recommendations. The co-chairs worked to set the appropriate discussions, themes, and topics for deliberation, but generally did not participate in the deliberations, decision making, or authorship of recommendations outside of the administrative process. Accordingly, this submission of recommendations to the Council on Climate Solutions does not constitute an endorsement or approval on behalf of the co-chairs, planning team, or their respective organizations.

### SOCIETAL IMPACTS AND IMPLICATIONS

Each of the templates developed for the 73 independent recommendations took a deliberate look at societal impacts of achieving its goal, including impacts on equity, environmental justice (EJ), labor, and workforce development. Decarbonizing Michigan's electricity and natural gas systems undoubtedly will have enormous environmental benefits, due to the direct carbon mitigation of fossil fuels. Attention to how to address the transition to a decarbonized energy system in an equitable way-- that which does not solely benefit affluent communities while leaving vulnerable and low-income communities behind -- has been paramount to the workgroup discussions.

To support workgroup discussions, the Workgroup invited Michigan's Environmental Justice Public Advocate to present to the group multiple times, providing foundational definitions of environmental justice<sup>4</sup>, and spending time educating on what is meant by equitable treatment and meaningful involvement. Furthermore, the Workgroup invited members of the Council on Climate Solutions Brain Trust to evaluate the group's preliminary recommendations in the middle of our process. The group made an intentional decision to invite these members to provide input while the process was still much in draft form, to help educate and articulate ways to truly consider community impacts and ensure they are built in to the foundation of the recommendations. The authentic feedback was influential on the development of the recommendations and these components became key drivers of the final recommendations.

### FINAL SURVEY

After final feedback was incorporated into the recommendations, a survey containing all 5 recommendations was sent out to the workgroup members to express whether they agreed with the final wording of each recommendation. Out of the approximately 150 total participants in the EPTDS workgroup, we received 33 survey responses. The respondents were not demographically representative of the overall makeup of the workgroup, so we have simply identified some themes that came back in the open-ended written comments from the survey that we feel may be valuable to the Council:

1. Multiple respondents said they felt the process was productive and valuable, and expressed that they were impressed with the final recommendations.
2. Multiple respondents said it was difficult to definitively say whether they agreed or disagreed with the overarching recommendations because there are too many distinct parts. Many stakeholders agreed with some parts of the recommendation, but not others.
3. Some respondents felt that the process for developing the recommendations was too fast and didn't allow for enough discussion and vetting of major issues by the subgroups. One respondent felt that much of the detail and nuance discussed in the subgroups had been lost in the act of simplifying, consolidating, and shortening into just 5 recommendations.

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<sup>4</sup> Michigan's definition of Environmental Justice: Environmental Justice is the equitable treatment and meaningful involvement of all people, regardless of race, color, national origin, ability, or income and is critical to the development and application of laws, regulations, and policies that affect the environment, as well as the places people live, work, play, worship, and learn. Equitable treatment means:

- no group of people bears a disproportionate share of the negative consequences resulting from governmental, industrial, or commercial operations and policies
- all people benefit from the application of laws and regulations
- eliminating barriers such as poverty and lack of access, as well as repairing systemic injustices
- Meaningful Involvement means: people have an opportunity to participate in decisions that affect their environment and/or health
- decision makers seek out and facilitate the involvement of those potentially affected
- people's concerns are considered in decision-making processes
- people can influence state agency decisions

Notably, much of the detail and value created by this workgroup is in the 73 individual recommendations (almost all of which contain their own detailed template), not just in the 5 summary recommendations. The breadth of these recommendations reflects that there is no silver bullet to achieving decarbonization, equity, and environmental justice.

## Appendix: 5 Lakes Energy Analysis

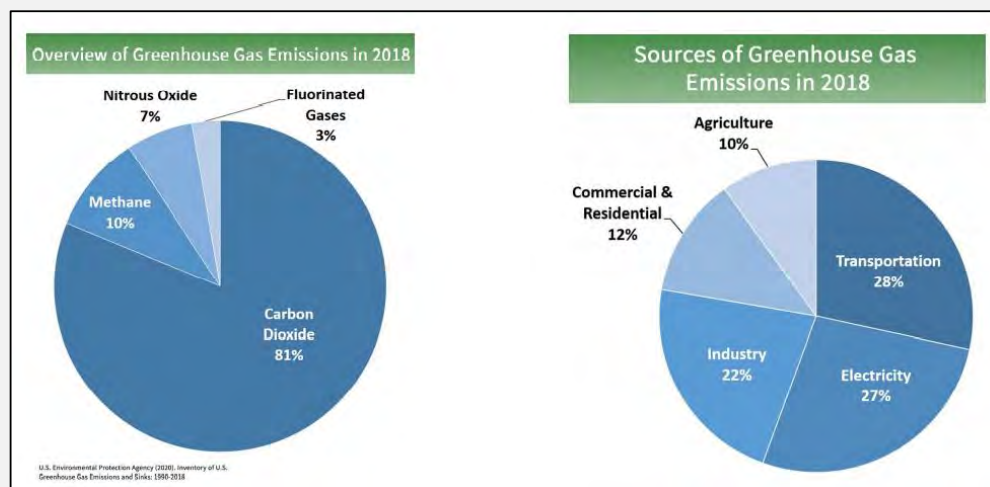
### Analysis of Michigan Greenhouse Gas Emissions Targets by 5 Lakes Energy

*The analysis within this appendix was completed by Douglas Jester of 5 Lakes Energy to provide additional context to the recommendations. The Michigan Public Service Commission does not endorse this analysis.*

Across sectors, cumulatively, Michigan has reduced overall emissions to 164.1 MMT or a roughly 14% reduction from the 2005 baseline. Pursuant to Governor Whitmer's Executive Directive 2019-12, Michigan joined the United States Climate Alliance. As noted in her Executive Directive 2020-10, this committed Michigan to pursue at least a 26-28% reduction below 2005 levels of GHG emissions by 2025. Subsequent changes in the United States Nationally Determined Contribution under the Paris Agreement and Michigan's continuing participation in the United States Climate Alliance commit Michigan to pursue at least 50-52% reduction below 2005 levels of GHG emissions by 2030.

In order to achieve the 28% by 2025 target, we will need a further reduction of 27 MMT or reduction of 16.4%. In order to reach the aggregate GHG emissions reductions needed of 68.8 MMT from 2018 levels to 2030 levels, each sector needs to set aggressive targeted reductions, which are reflected in the working group's recommendations. However, even with aggressive targets, we can only reasonably expect the other sectors (residential, commercial, industrial, and transportation) comprise 22 MMT reduction, leaving the remaining 46.8 MMT reduction responsibility to the electric power sector.

**Figure 2: Greenhouse Gas Emissions**



To fully understand trends of current inventory of GHG emissions in MI, it is important to note two observations from this chart. First, Carbon Dioxide (CO<sub>2</sub>) is by far the largest share of greenhouse gases, and second, the electricity, transportation, building heat, and industrial sectors roughly contribute equally, around 25% each, to total sources of GHG emissions in MI.



While we can expect some incremental changes in each of the sectors over the near term, the onus largely falls on the electric power sector to develop solutions to significantly reduce carbon dioxide emissions. The subsequent chart shows projected estimates of achievable carbon dioxide reductions from each industry, with the largest burden falling upon the electric power sector. The projected estimates of achievable carbon dioxide emissions reductions are based on aggressive electrification of transportation and heating, but near-term reductions in carbon dioxide emissions are limited by the relatively slow turnover of equipment in use, with the average age at which vehicles and heating equipment are retired being in the range of 15-20 years. These projections are not proposed as the “optimal path” to achieve this level of GHG emissions reductions, but as indicative of what will be necessary.

**Figure 3: Michigan Emissions By Sector 2030-2018% Change**

| Michigan Carbon Emissions<br>2030-2018 (million metric<br>tons) | Residential<br>Sector | Commercial<br>Sector | Industrial<br>Sector | Transportation<br>Sector | Electric Power<br>Sector | All Sectors |
|-----------------------------------------------------------------|-----------------------|----------------------|----------------------|--------------------------|--------------------------|-------------|
| Coal                                                            | 0.0                   | 0.0                  | -5.0                 | 0.0                      | -43.2                    | -48.2       |
| Petroleum Products                                              | -0.2                  | -0.1                 | -1.2                 | -13.1                    | -1.6                     | -16.2       |
| Natural Gas                                                     | -1.9                  | -0.8                 | 0.5                  | -0.3                     | 0.0                      | -2.5        |
| Total                                                           | -2.0                  | -0.9                 | -5.7                 | -13.4                    | -44.8                    | -66.8       |
|                                                                 |                       |                      |                      |                          |                          |             |
| Michigan Carbon Emissions<br>2030-2018 (% change)               | Residential<br>Sector | Commercial<br>Sector | Industrial<br>Sector | Transportation<br>Sector | Electric Power<br>Sector | All Sectors |
| Coal                                                            |                       |                      | -100%                |                          | -100%                    | -100%       |
| Petroleum Products                                              | -6%                   | -8%                  | -30%                 | -25%                     | -100%                    | -26%        |
| Natural Gas                                                     | -10%                  | -8%                  | 5%                   | -25%                     | 0%                       | -5%         |
| Total                                                           | -10%                  | -8%                  | -30%                 | -25%                     | -76%                     | -41%        |

## Summarized Recommendations

Below, we have summarized each of the overarching recommendations. More detailed versions of each recommendation follow. The recommendations have been numbered for reference purposes only; the numbers do not reflect a ranking or prioritization unless otherwise noted.

1. **Implement holistic and integrated energy system planning:** The Michigan Public Service Commission (MPSC) should implement a series of measures towards more holistic and integrated energy system planning in Michigan. This should include traditional resource planning, long-range transmission planning, distribution planning, storage planning, consideration of new and emerging resources, planning around areas of interdependency between the electric and natural gas systems, and consideration of community and health impacts.
2. **Enable behind-the-meter resources:** Advance policies that enable behind-the-meter resources, demand control, and demand flexibility including rooftop solar, electric vehicle aggregation and vehicle-to-building and vehicle-to-grid technologies, microgrids and off-grid capabilities, energy storage, and enhanced energy productivity and energy waste reduction while utilizing low-cost financing and prioritizing low-income and environmental justice communities.
3. **Explore innovative rate designs:** Explore innovative rate design concepts, including studies and other considerations in the design of customer rates as decarbonization efforts progress.
4. **Facilitate siting of necessary energy infrastructure:** Adopt state policies and programs that will facilitate siting of necessary renewable generation, storage, and transmission sufficient to achieve a clean energy transition of the electric power sector.
5. **Evaluate gas system regulatory and policy options:** The governor should direct EGLE and/or the Michigan Public Service Commission to initiate a staff-run stakeholder group or proceeding to evaluate opportunities and considerations for changes to gas utility regulatory and policy structures needed to support cost-effective and equitable achievement of the state's economywide greenhouse gas reduction goals.

## Detailed Recommendations

The following pages provide a rationale, detailed background, and savings projections for each of the five overarching recommendation themes. Within these themes, in response to the last question in the recommendation template, numerous sub-actions are listed. These sub-actions reflect the 73 recommendations that came out of the subgroup discussions.

The recommendations have been numbered for reference purposes only; the numbers do not reflect a ranking or prioritization unless otherwise noted.

### I. Implement Holistic and Integrated Energy System Planning

#### 1) Overview of recommendation.

Rationale: In order to achieve economy-wide net zero emissions by 2050 and necessary interim targets, we will need to plan for strategic alignment among resource, distribution, transmission, and storage planning. Traditional integrated resource planning (IRP) includes developing numerous scenarios and sensitivities to various utility futures, though is limited to only the electric side of utilities and has specific constraints developed in law, under PA 341. While these requirements are due to be revisited in 2022, it is recommended that the Council on Climate Solutions considers utility planning, resource adequacy and reliability more holistically, such as the impacts of transmission and storage on the system as well as considering how to cost effectively decarbonize the natural gas system. In addition, to fully plan for strategic alignment of the energy system, it is essential to ensure that the transition occurs in an equitable manner. To that end, specific additional considerations of externalities like the social cost of carbon, geographic considerations like assessment of environmental justice communities, climate resiliency planning, and local community impacts should also be included for a more holistic look toward the future.

Recommendation: The Michigan Public Service Commission (MPSC) should implement a series of measures towards more holistic and integrated energy system planning in Michigan. This should include traditional resource planning, long-range transmission planning, distribution planning, storage planning, consideration of new and emerging resources, planning around areas of interdependency between the electric and natural gas systems, and consideration of community and health impacts. This will require the implementation of a number of different changes to electric and natural gas utility planning, as detailed below. Importantly, a number of these are preliminary recommendations that should be provided to MPSC staff for consideration as they begin the stakeholder process to revise MI Integrated Resource Planning Parameters and Filing Requirements.<sup>5</sup> The changes to be considered in support of more holistic and integrated energy system planning and encourage continuous improvement with all planning activities in Michigan should include the following:

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<sup>5</sup> [MPSC - Phase III - Integrated Resource Plan \(MIRPP, Filing Requirements, Demand Response Study, Energy Waste Reduction Study\) \(michigan.gov\)](#)

- A. Updates to IRP Modeling-** Improve and modernize Michigan's integrated resource planning process by streamlining the scope in some places and broadening it on others, including the following:
- i. Explore streamlining the Environmental Policy (EP) and Emerging Technology (ET) into one scenario. Ensure thoughtfulness in specifying scenarios in the MIRPP collaborative so only non-duplicative scenarios that add valuable information to the IRP are specified.
  - ii. Reduce the number of the required sensitivities and allow the utility to work with stakeholders through an informal process to develop any extra sensitivities.
  - iii. Utilities should submit their outputs from IRP modeling as a \$/ton CO<sub>2</sub> reduced calculation to compare various alternatives and to compare between plans in their filed IRP.
  - iv. Utilities should be required to consider the most promising emerging technologies in their IRPs, such as Natural gas CCS, Biomass CCS, Biologic Direct air capture, energy storage (including long-duration energy storage), plus others.
  - v. Treat Rate Design as a resource in the IRP, separate from Demand Response. Rate designs may be flat with or without demand charges, time of use, or dynamic rates.
  - vi. Ask utilities to include a sensitivity or risk analysis projecting potential increased load due to climate change (e.g., increased load due to projected future temperature increases) to support resiliency planning of supply resources.
  - vii. Require utilities to fully consider externalities of all technologies (including use of foreign and out of state components, Michigan labor, full lifecycle emissions and costs including disposal, effects on migratory birds, bats, and insects, 45-Q Tax credits) in their IRP modeling.
  - viii. Emerging and some existing technologies have the potential to enhance carbon reductions beyond the traditional onshore wind, solar, and storage technologies and should be appropriately vetted in the IRP process.
- B. Improve Transmission Planning-** Better integrate Integrated Resource Planning and transmission planning through the following measures:
- i. Align Integrated Resource Planning scenarios with transmission planning scenarios used by MISO. Using these futures allows for aligned planning, provides baseline market expectations across the region and an understanding of how the market will impact Michigan and utility resource decisions to ensure resource adequacy.
  - ii. The MPSC, in coordination with the Michigan transmission owners and utilities, should ask the applicable RTO to conduct 20-year forward-

looking transmission studies to identify needed transmission infrastructure to address economic, reliability, and energy adequacy issues arising from anticipated generation additions (including location, scale, and timing) and retirements, as well as load changes due to electrification and growth in energy efficiency and demand response programs, and evaluate resulting GHG emissions reductions achievable in pursuit of Michigan's carbon neutral by 2050 goal.

- iii. The MPSC, in coordination with the Michigan transmission owners and utilities, should define "resilience" from a grid planning perspective and ensure that MISO and Michigan utilities are studying low-probability, high-impact events, including the effects of climate change on the magnitude and frequency of extreme weather events.
- iv. The MPSC should express continued support of regional transmission in RTO processes to support the state's carbon neutral by 2050 goal and other state policies and seek to remove barriers and obstacles to the regional transmission planning process
- v. IRPs should take into account transmission planning through a more holistic approach than just working with ITC and plan at the MISO level.
- vi. In order to prepare for a transmission grid that is fully prepared to take on the increased renewable energy generation coming online, the Governor and MPSC should increase their efforts for MISO to plan for a high renewable future.

**C. Incorporate Holistic Natural Gas Planning-** Broaden integrated resource planning and support a holistic decarbonized energy system through the following measures:

- i. There should be a natural gas "IRP" planning process created, and the electric IRP process should refer to this future gas plan and vice versa to avoid misalignment between plans.
- ii. IRP modeling currently searches for the resource plan that has the lowest net present value of utility required revenue and meets various constraints, including serving all load, meeting MISO/Michigan resource adequacy standards, and various environmental regulations. At least one scenario should be modeled to minimize the net present value of the sum of utility revenue plus externalities (calculated as the social cost of emissions from power generation and of any changes in emissions due to electrification of transportation and heat) to find the optimal pace of decarbonization of power generation and of utility efforts to electrify transportation and heating.

**D. Align Distribution Planning -** Better integrate resource planning with distribution planning by incorporating co-optimization of distribution system planning and benefits in IRPs. This process should occur in a formal contested

case to ensure more visibility and accountability for the utilities' distribution planning process. Meaningfully consider public health and equity to ensure that resource planning processes consider impacts on communities and health by implementing the following measures:

- i. Require utilities to conduct a Health Impact Assessment for each model run required by the Michigan Public Service Commission and each scenario or pathway proposed by the utility.
  - ii. Require utilities to identify environmental justice communities in their service territory and to describe how they are minimizing environmental risks and promoting equitable access to the utility's services and programs in such communities.
  - iii. Require that IRPs consider the goals of the communities that they are serving, help the communities achieve those goals, and ensure that lower income people are not subsidizing that work.
- E. **Direct Storage Procurement-** Direct the Michigan Public Service Commission to explore possible structures to incentivize novel energy storage technologies (i.e. set amount of new generation resources, as non-wires alternatives, the addition of X amount of MWs) that can be adopted voluntarily by utilities and/or provided for consideration by the Michigan legislature.
- F. **Plan for State Carbon Reduction Goals** - Ensure that planning is achieved in a way that meets the state's goals and commitments for carbon reduction. One way to achieve this is through a more aggressive renewable portfolio standard.

**2) In what timeframe is this recommendation achievable?**

Multi-Step Process: Many of the elements of this recommendation will take multiple years to execute and fully synchronize the coordination of multiple parties and stakeholders. Those recommendations that include revisions to the MI Integrated Resource Planning Parameters (MIRPP) and IRP Filing Requirements may occur as early as the 2022 timeframe, though would likely not be implemented until the end of 2027 (the second cycle of IRPs) and full implementation by 2032 (the third cycle of pilots). Since IRPs are on separate and staggered timeframes for each utility the implementation timeframes would also be staggered, but the coordination efforts can begin in the near term.

**3) What is the relative magnitude of this recommendation, in terms of GHG emissions reductions?**

Improved regional modeling can lead to more consistency in resource planning, which and should ultimately reduce emissions across the state's footprint. With a more aggressive renewable portfolio standard and/or additional state carbon reduction goals, holistic planning can directly work toward achieving the metrics put forth by the states.

**4) Describe the potential impacts of this recommendation on environmental justice.**

There are numerous ways which communities that are affected by traditional EJ issues, such as the burden of fossil fuel pollution, could benefit from the recommendations included in holistic planning of the power sector. Communities could experience the benefits of reduced emissions and other impacts of plant closures, which underscores the need for community outreach when developing closure plans, potential site redevelopment, and siting of new resources. Replacing generating resources with renewable energy resources will help build a more reliable, resilient, and economic electric system, with a reduction in harmful impacts on vulnerable populations.

**5) Describe the potential impacts of this recommendation on labor.**

As the energy system undergoes substantial transition with the continued closure of coal and other fossil fuel plants, there will be some immediate loss of tax dollars in communities and reciprocal impacts on labor. 20-year forward looking transmissions studies could help to unlock the potential of 8,000-10,000 MW of renewable generation and other technologies to support a net-zero carbon power system, which could have positive impacts on labor in terms of job-creation.

Right sized transmission infrastructure could help create long-term sustainable jobs, which will escalate over the next several years with a duration that will likely surpass 20 years, requiring a skilled and dedicated workforce.

**6) Describe the potential impacts of this recommendation on the environment.**

A decrease in emissions from legacy fossil fuel generation through more intentional long-term planning processes will help to improve air quality over time and effective land-use planning. Holistic planning toward state carbon reduction goals will move the power sector toward clean and renewable forms of energy, and away from traditional fossil fuel resources that have serious environmental impacts.

**7) Describe the potential impacts of this recommendation on economic development.**

Renewable energy attracts new industry; investment in areas of transmission and storage have the long-term potential of reducing electric rates. The marginal cost of most net-zero energy generation is much lower than the marginal cost per kWh of traditional fossil fuel plants. Connecting transmission resources helps to better “connect” with our neighbors and ensure Michigan has the needed infrastructure to support carbon-neutral goals. The elements of this goal that have to do directly with building out infrastructure such as transmission lines and expanding renewable energy would have positive economic development impacts through construction and maintenance jobs.

**8) What are the relative costs of this recommendation?**

The recommendations having to do with improved coordination and alignment have minimal cost. These recommendations would require coordination and study work largely utilizing existing resources.

Combining or streamlining some modeling scenarios and associated sensitivities will help improve efficiency. Each additional scenario can add 4 to 6 weeks to the process, and this recommendation would in fact lower costs.

Regulated utilities in Michigan are already required to conduct an IRP every 5 years; this recommendation specifies the scenarios they would be required to model with the ability to conduct utility-specific scenarios if they desire to. This has no cost.

**9) Who is empowered to implement this recommendation?**

Much of the responsibility to implement this recommendation falls on the Michigan Public Service Commission to order utilities to amend their processes. Some of the responsibilities will fall onto the private sector – namely the investor-owned utility companies and transmission owners – to cooperate with alignment efforts.

**10) Is there consensus among the subgroup for this recommendation, or are there differing perspectives? If differing perspective, what are they?**

There are numerous conflicting perspectives on each of the sub-recommendations contained within holistic planning that are included in the separate workgroup templates and too lengthy to list all here. Per a preliminary assessment, there were 2 sub-recommendations that had full support, 8 sub recommendations that had majority support, 5 which were neutral, and three which had some opposition. Here are some examples of the notable controversial views raised:

Improve Transmission Planning: there are significant jurisdictional complexities to this proposal; integration could result in delays and MISO remains the best conduit for stakeholders to participate.

Holistic Gas Planning: Natural gas remains the most efficient and cost-effective fuel for customer's safety during cold Michigan winters. Significant technological advancement and cost reductions would be needed from prevailing technologies to minimize customer cost impacts to transition away; robust and transparent cost benefit analysis should be completed prior to any policy objective that calls for moving away from, or limiting natural gas heating in Michigan.

Regarding Coal and Gas Generation: The shift away from coal will continue to result in sunk costs; replacing gas that will need to be phased out in the future continues to come with sunk costs. We should be facilitating a transition to clean resources that continues to ensure reliability to customers. While alignment with the Biden Administration's goal is important, it may be unfair to put all the pressure on the power sector because it may lead to increased sunk costs in the name of meeting an interim goal. What's more important is facilitating those measures that help utilities learn to run a cleaner electric grid in the long term.

Align Distribution Planning: Cases where planning takes place should remain separate from cases with a particular provision for cost approval.

Accounting for Externalities: There were several complexities raised within the subgroup discussions including the following: 1. What type of model would be used to account for



externalities? 2. Since the MPSC cannot dictate how utilities are run, incentives vary by utility and type of customers; 3. Cost of service in rate cases vs. IRP cases – where does this specifically fall for vehicles or the transportation sector? 4. Incorporating the heating sector into IRPs is complex; 5. The large IOUs take issue with the specifics of how and which modeling is used prior to implementation.

Some groups would like to push for an even more aggressive target of achieving carbon-free electric power. For instance, commenters submitted the following language:

In order to align with the Biden Administration's emission reduction strategies and to set Michigan on an accelerated path toward mitigating the effects of climate change, Michigan should revise its target to 80% carbon-free electric power by 2030.

- A. Retire all Michigan's remaining coal-fired plants by 2030
- B. No new gas-fired power plant development.
- C. Establish a Renewable Portfolio Standard of 60% by 2030, with ramping up targets in 2035 and 2040 commensurate with Michigan's goal of reaching 100% carbon-free power by a date certain.

**11) What are the most important considerations for achievability and feasibility of this recommendation?**

The goals contained within this recommendation are complex, long-range, and will require plenty of coordination between regulators, utilities, transmission owners, developers and other business interests, as well as engagement with the advocate community. Planning for the future requires an understanding of the impacts, goals, and developments beyond Michigan's borders. This understanding of alignment of planning across resource and transmission development facilitates holistic grid solutions that help MI achieve a path toward a carbon-free future.

Several of the concepts discussed here fit squarely into upcoming conversations to take place as part of the MPSC's MI Power Grid Phase Three Advanced Planning process. Electric utilities are required to file plans every five years with the MPSC that look at anticipated customer electricity needs over the next 5, 10, and 15 years. The MPSC establishes parameters and filing requirements for utility integrated resource plans and conducts studies on achieving energy waste reduction and demand response.

In addition, the Governor's ED that directs the MI Healthy Climate plan includes the following language:

Expand its environmental advisory opinion filed by [EGLE] in the Michigan Public Service Commission's Integrated Resource Plan process under MCL sections 460.6t and also file environmental advisory opinions in IRPs filed under MCL 460.6s. [EGLE] must evaluate the potential impacts of proposed energy generation resources and alternatives to those resources, and also evaluate whether the IRPs filed by the utilities are consistent with the emission reduction goals included in this Directive. For advisory opinions relating to IRPs under both

MCL 460.6s and MCL 460.6t, [EGLE] must include considerations of environmental justice and health impacts under the Michigan Environmental Protection Act. The Commission's analysis of that evidence must be conducted in accordance with the standards of the IRP statute and the filing requirements and planning parameters established thereto.

Many of the issues discussed in these recommendations discussed in the Holistic Planning theme build upon concepts included in the MI Power Grid Phase Two work. Per MPSC Order in Case No. U-20633, Staff is to initiate a redline draft of revised MIRPP and filing requirements and share with stakeholders by Dec. 22, 2021; a stakeholder process will follow which provides ample opportunity to incorporate several of these recommendations.

Some other complications to consider:

- A. Neither the Emerging Technology nor Environmental Policy scenarios currently reflect the Governor's GHG goals. This is an opportunity to streamline the State's GHG reduction goal into an integrated scenario. This could be accomplished through MIRPP Advanced Planning.
- B. GAS IRPs: Other states are pursuing Gas IRP type planning such as, Minnesota and Colorado indicating it is feasible and achievable implement.
- C. This is a long and complicated process. By the second cycle of IRPs (2023/2025) minor adjustments could be made to refer to a Gas IRP, however the level of fully mature integrated planning necessary to create a unified gas and electric plan is expected to require additional time beyond the second cycle of IRP filings. Full alignment could take many years to negotiate.
- D. Much like transmission infrastructure, only a fraction of the gas infrastructure is regulated by Michigan. This recommendation would need to consider those federally-regulated lines where gas passes through Michigan to some other destination, therefore it is unclear about how a "gas IRP" would be performed in the context of a utility IRP. Certainly the availability of gas can be contemplated in an IRP and the closure of gas lines can be contemplated in a gas rate case.

## **II. Enable Behind-the-Meter Resources**

### **1) Overview of recommendation.**

Rationale: Greatly increased renewable energy generation plus energy storage is a given requirement for achieving the goal put in front of the Council on Climate Solutions of carbon neutrality for the state. This will require new, innovative approaches to achieving load balance and fair compensation for grid services. Additionally, the effects of the already changing climate, in the form of increased extreme weather, must be mitigated via improved reliability and resiliency. This recommendation attempts to address both increasing usage of clean electricity generation and guarding against the

impacts of climate change, while uplifting and protecting the most vulnerable populations and historically disadvantaged communities.

Recommendation: Advance policies that enable behind-the-meter resources, demand control, and demand flexibility including rooftop solar, electric vehicle (EV) aggregation and vehicle-to-building and vehicle-to-grid (V2X) technologies, microgrids and off-grid capabilities, energy storage, and enhanced energy productivity and energy waste reduction (EWR) while utilizing low-cost financing and prioritizing low-income and environmental justice (EJ) communities. Specific actions include:

- A. Eliminate the solar distributed generation (DG) cap to allow for individuals to install solar panels that can serve both their residence and the larger electric grid with carbon-free power at low cost
  - i. This would have the result of incentivizing more solar developers to enter the Michigan market, increasing competition and financing options, and reducing upfront and maintenance costs;
- B. Update the DG avoided cost calculation to better value solar generation and encourage private development of rooftop solar;
- C. Update and expedite the grid interconnection process for all technologies, including distributed solar, solar + storage, and electric vehicles with V2X capabilities;
- D. Enable tax benefits and/or purchase credits for all renewable and storage projects, regardless of size and ownership;
- E. Expand MI Saves funding and enable on-bill "pay-as-you-save" and other financing for distributed energy resources (DERs), but with both appropriate safeguards and direct funding support for low-income customers who are often unable to assume and/or manage additional debt;
- F. Expand and enhance existing EWR, DR, and DER programs, particularly for low-income communities, including:
  - i. Pairing electrification programs with residential DR, managed charging, and other peak reduction measures;
  - ii. EWR programs for the most efficient and affordable home heating and appliance technology, including efficient heating, grid connected appliances, and weatherization measures that reduce heating loads/needs;
- G. Incentivize automated energy management through new and existing AMI infrastructure, and fully utilize the data available to better match generation to load with clean resources;
- H. Expand energy storage and battery purchase and lease programs;
- I. Enact policies to support EV V2X integration programs by allowing vehicles to alter charging time, charging level, or location at which they can charge or discharge, in a manner that optimizes plug-in electric vehicles' interaction with the electrical grid and provides net benefits to ratepayers by doing any of the following:

- i. Increasing electric grid asset utilization,
  - ii. Avoiding unnecessary distribution infrastructure upgrades,
  - iii. Integrating renewable energy resources,
  - iv. Reducing the cost of electric supply;
- J. Support development and management of vehicle load aggregation programs to support balancing of load in an utility service area. Adopt programs that allow utilities to offset loss of battery capability and warranty through periodic usage-based rebates to customers and/or OEMs.
- K. Allow microgrids for electrically contiguous sites, allowing for greater procurement of renewables, shared energy storage resources, and greater resilience. Establish uniform interconnection standards and rates that reflect the cost of service and do not include unnecessary charges.

**2) In what timeframe is this recommendation achievable?**

This recommendation includes a series of distinct elements for implementation, many of which will take multiple years to execute and fully synchronize the coordination of multiple parties and stakeholders. Some of the elements could be implemented relatively quickly. Others require the legislature to make changes to statute.

**3) What is the relative magnitude of this recommendation, in terms of GHG emissions reductions?**

There are many parts to this recommendation that could have a large impact on GHG reductions by switching electric generation source from fossil fuels to renewables, shaping demand to rely more on clean sources, and reducing waste of energy produced. This could be a primary driver to reduction of the electric sector's GHG emissions.

**4) Describe the potential impacts of this recommendation on environmental justice.**

The burden of fossil fuel pollution has fallen traditionally on EJ communities, and by enabling BTM, demand response, demand control, and demand flexibility resources, there will be reduced need for these traditional fossil fuel resources, particularly the most polluting peaking plants. Communities could experience the benefits of reduced emissions and other impacts of fossil fuel plant closures. Replacing generating resources with DERs, EWR, and demand flexibility will help build a more reliable, resilient, and economic electric system, with reduced harmful impacts on vulnerable populations. Expanding and enhancing funding, financing, and direct support for low-income communities will allow these benefits to go directly to the communities that need them most and have been historically disproportionately impacted by our current grid and the changing climate.

Through enhancing and expanding EWR programs, the energy burden on low-income households can be reduced. Additionally, lower income communities have traditionally not had the resources to improve their own electric reliability, such as by buying a

backup generator. Through enabling deployment, financing, and direct support for microgrids, DERs, rooftop solar.

**5) Describe the potential impacts of this recommendation on labor.**

As the energy system undergoes substantial transition with the continued closure of coal and other fossil fuel plants, there will be some immediate loss of tax dollars in communities and reciprocal impacts on labor. This transition will need to be managed closely.

Labor opportunities will grow for the development of DERs, microgrids, residential energy storage, and V2X infrastructure.

EWR programs will require added labor for implementation, whether for installation of efficient heating, grid-connected appliances, and installation of weatherization measures in homes and buildings.

**6) Describe the potential impacts of this recommendation on the environment.**

Reducing peak demand via DR, demand flexibility, and demand control will lower the need for generation during peak times. Often times, the traditional power plants used to serve peak loads are the heaviest polluting, with the most lenient emissions controls. Grid flexibility is important to reducing emissions so load can be matched with the cleanest generation technologies.

Increased DER deployment in the form of rooftop solar and energy storage will replace the generation needed from legacy fossil fuel generation and replace it with zero carbon sources.

Supporting electric vehicles and V2X capabilities will reduce emissions from transportation, while simultaneously enabling residential energy storage and supporting renewable generation sources.

**7) Describe the potential impacts of this recommendation on economic development.**

Advanced energy attracts new industry; investment in DERs, microgrids, energy storage, grid-connected appliances, and other new technology creates jobs both through technology development, but also through service and installation requirements.

Advanced energy has the long-term potential of reducing electric rates for ratepayers since the marginal cost of net zero energy and emission producing generation will grow.

Demand for electric vehicles through expanded V2X programs will boost the automotive industry.

**8) What are the relative costs of this recommendation? Unknown, or different timeframe – explain why:**

The costs to taxpayers would be in the form of tax benefits, purchase credits, funding, and financing costs for the programs outlined. The costs will need to be further analyzed in implementing these recommendations and cannot be estimated at this level.

**9) Who is empowered to implement this recommendation?**

Much of the responsibility to implement this recommendation falls on the State Legislature and some on the Michigan Public Service Commission.

**10) Is there consensus among the subgroup for this recommendation, or are there differing perspectives? If differing perspectives, what are they?**

There were differing perspectives noted during subgroup discussions and via comment, noted below:

- Utility scale solar should be pursued instead of BTM solar
- Grid interconnection process should not be focused on distributed resources
- On-bill financing should only be available for participants in utility programs, not for financing outside of utility programs
- Do not allow microgrids, as it appears to be a way to get around the ROA cap
- Do not recommend electric vehicle aggregation
- Do not recommend off-grid capabilities, as it is inconsistent with reliability and resiliency
- Points A and B should be updated to reflect a more balanced viewpoint on these issues which have been repeatedly discussed in legislative and regulatory venues. BTM solutions are already enabled in policy and regulation under MI statute. The “cap” does not correlate with emission reductions; it simply creates a threshold for a quantity of customers to receive a specific rate. Utilities are required to continue interconnecting BTM systems regardless of this threshold. Recommendations should not expressly incentivize one technology over another, but set a foundation around market-based dynamics and price signals, as well as align with current distributed generation policy.
- Rate design should be aligned with the cost to serve customers and should not be used to pick technology winners
- Need to ensure that EWR, DR, and DER programs are cost effective for customers
- Any changes to microgrid structures must respect the utility franchise agreement
- Elimination of the solar distributed generation cap could result in reduced reliability of the grid in the near and medium terms and ultimately result in increases in necessary distribution facility capital investments by incumbent distribution utilities to enable the distribution systems to safely accommodate the bidirectional flow of power. Such a policy would increase costs for all customers, including seniors and lower income customers who may not have the means or inclination to invest in a distributed generation system of their own. The distribution system in Upper Peninsula would likely see a magnified impact due to the reduced density of the customers and energy flow analyses would be very important to ensure reliability.
- “Pay-as-you-save” financing and on-bill financing would increase administrative costs that would need to be paid by all utility customers to manage proper collection and administration of these lending relationships. This would be

particularly impactful to smaller utility customers because they don't have the scale that would support the fixed costs associated with such programs.

- Requirement of opt-out, time-varying rates could result in increased volatility in customer bills and negatively modify the customers' relationship due to customers' likely perception that the utility made these changes to the TVR rates. Furthermore, it could increase customer bills and have the opposite effect to the apparent objective for customers that are not able to or unwilling to modify their behavior with respect to how they consume energy. TVR where customers have the ability to opt into allows customers to self-identify as sophisticated users of energy and willing to actively manage their energy consumption to minimize their bills.

**11) What are the most important considerations for achievability and feasibility of this recommendation?**

Much of the success for the recommendation comes down to coordination, coordination, and shared goals between the state executive branch, the state legislature, the MPSC, and Michigan's utilities. In particular, the political will of the state legislature will be required to enable much of the recommendation outlined. For example, the current level and functioning of the DG cap is set in statute by the legislature, and would need to be amended there before it could be implemented by the MPSC. The DG avoided cost calculation is similarly set by the legislature and would need to be amended and implemented in a similar fashion. The law preventing microgrids across property boundaries is set by statute as well, and would require consensus in the legislature that the development of microgrids is a net benefit to customers, and will then require coordination between the legislature and the MPSC in order to be implemented and projects rolled out.

The grid interconnection process would need to be modified by the MPSC and utilities together, as well as EWR and DR programs and the utilization of AMI infrastructure for matching load to generation.

Funding for MI Saves, on-bill financing programs, and other financing, lease, and direct support programs would need the support of the State or Federal budget.

Ultimately, there needs to be some agreement on the pathway from those making the laws and regulations and stakeholders – including utilities – for this to work.

For further discussion on considerations for achievability and feasibility of this recommendation, see the detailed sub-recommendations connected in the Airtable.

### **III. Explore Innovative Rate Designs**

**1) Overview of recommendation.**

Rationale: Rate design is a critical element in the efforts to decarbonize. As the energy transition evolves in many ways, including away from baseload resources to cleaner and intermittent resources in efforts to reduce greenhouse gas emissions, electricity and

natural gas rate design must be reformed to ensure a stable transformation. For example, customer owned behind the meter resources, third party energy providers, and other distributed energy resources draw revenues away from the traditional utility framework in which revenues are collected by utilities and customer rates are founded on. Customers continue to have more rate options available to them, such as time-of-use pricing and specific rates for customers with electric vehicles, to encourage more effective usage off-peak. However, the needs of both customers and utilities will continue to be challenged and innovative rate design will be essential as technology and decarbonization solutions are deployed. Further, the energy transition and specifically rate design must promote equitable access to the benefits of clean energy and ensure the most vulnerable customers are uplifted and protected.

Recommendation: Explore innovative rate design concepts, including studies and other considerations in the design of customer rates as decarbonization efforts progress. Efforts should include the following:

- A. Require all investor-owned utilities to adopt an opt-out, time-varying rate (TVR) program and ensure all participating customers have smart meters installed. To further encourage energy waste reduction, grid modernization, and peak demand shifting, offer state and utility-driven incentives to encourage customers to purchase home energy management systems (HEMS). Consider partnering with municipal utilities and electric co-operatives, or requiring them through legislation, to adopt similar programs. Reducing system-wide peak demand through a combined TVR, smart meter, HEMS approach will reduce the need for Michigan's fossil-fueled peaking plants, which are often located in or near communities of color. As a result, the subsequent drop in demand will contribute to better air quality and lower respiratory disease rates in these neighborhoods. Additionally, lowering peak demand and installing HEMS in low-income homes/rental units will make energy more affordable in the long-term. Utilities should utilize the full functionalities of AMI during real-time operations and focus on customer education.
- B. The legislature should require all electric service providers (investor owned, cooperatives, municipal, etc.) to unbundle their rates, clearly differentiating between the energy charge (comprised of a \$/kWhr amount and a \$/kW demand charge amount) and the distribution charge (which reflects the providers O&M for distribution) for all rate structures. This will provide energy users with information they need in order to manage their loads and offers demand side flexibility. Charges should also be simplified and crafted to ensure customers can appropriately understand and react in the most efficient manner possible.
- C. To achieve broader electrification, an equity and low-income lens must remain a top priority. In addition to program efforts to reach low-income customers, it is recommended that utilities study and offer:
  - i. Electric or natural gas rates based on percent of income, rate subsidies for low-income customers, or even net-zero cost of electricity or natural



gas for low-income customers (subsidized usage capping is one option or based on the rating of the energy efficiency of the building);

- ii. Those receiving subsidized rates would also be connected to an enhanced EWR program;
- iii. Expand and improve energy assistance programs;
- iv. Flexible payment programs;
- v. Rebates and carve-outs for low-income customers;

As new rates are designed, utilities must make a real commitment to customer education, especially for low-income customers. Customers should be offered rate options that are the best for their circumstance and needs. Movement to a new rate should be intuitive, simple, and mitigate the need for customers to fill out forms.

- D. Require utilities to collect race, income, and geographical-based information regarding billing as well as the implementation, participation, and marketing of key utility programs in order to identify race and income-based inequities in utility operations.
- E. Align electric rate design with electrification goals. Electric rate designs should be structured to better reflect the marginal cost to the grid of adding new electrified loads, particularly added loads that are optimally managed or controlled. Such rates are expected to be much lower than current average rates per kWh. The MPSC, utilities, and other parties should explore whether and the extent to which changes to advanced metering infrastructure technologies may help support such efforts. Electric vehicle line extension policies, and potentially other line extension/connection policies, should be reviewed and potentially updated in order to accelerate EV adoption.
- F. Integration of new rate design should include a new rate paradigm for distributed energy resources, which incentivizes the construction of DERs and values carbon dioxide reduction, but maintains current cost of service requirements among the rate classes.
- G. Explore performance-based regulation and ratemaking methodologies. Review and revisit the utility monopoly construct and amend to reflect what no longer fits the regime going forward.
- H. The potential of stranded assets in the natural gas or electric sector should be addressed in rate design and ensure those costs, if they occur, are distributed equitably.
- I. Require the utilization of securitization or other forms of recovery for early retirement of power plants or stranded assets during the energy transition. Securitization will lessen the cost impact on ratepayers.

- J. Require all investor-owned utilities to adopt and offer EV time-of-use rates to encourage and spur EV adoption in the state. Further allow the OEMs to report EV charge data directly to the utilities without the need of a separate sub meter. This will lower the upgrade cost to the customer switching to an EV.

**2) In what timeframe is this recommendation achievable?**

Rate design can begin immediately. Other studies and pilots may take two to five years for study, analysis, and implementation.

**3) What is the relative magnitude of this recommendation, in terms of GHG emissions reductions?**

Rate design will not have a direct impact on GHG emissions, but will be a major factor in achieving GHG reductions. It can be thought of as a necessary and enabling tool for GHG reductions in the energy sector.

**4) Describe the potential impacts of this recommendation on environmental justice.**

Low-income households are disproportionately likely to suffer from higher energy burdens, more likely to live in less efficient housing, and more likely to rent their homes. Rate design will have to be intentionally crafted and innovative to ensure inequities are marginalized in decarbonization and clean energy efforts and that vulnerable customers are not abandoned, the last to transition, or left footing the bill.

Thoughtful rate design has the potential to significantly impact and improve environmental justice and equity directly. Rates can be designed based on historic advantage/disadvantage, poverty level thresholds, and to lift up particular zip codes or communities that are in need or disproportionately impacted by the changing climate. Thoughtful and well-designed rates can have a direct impact in the short term.

**5) Describe the potential impacts of this recommendation on labor.**

Rate design studies can be performed and shared widely with other states. It opens the opportunity for creativity and data collection. There is not a large impact on labor, but reaching out to industry experts, researchers, and universities may be beneficial.

**6) Describe the potential impacts of this recommendation on the environment.**

Proper rate design can have indirect benefits by the potential to lead to a quicker and smoother clean energy transition.

**7) Describe the potential impacts of this recommendation on economic development.**

Suitable rate design will drive adoption of electrification investments, which can generate economic activity related to construction, retrofits, and electric infrastructure development. Competitive energy prices will also attract businesses to Michigan.

**8) What are the relative costs of this recommendation? Unknown, or different timeframe – explain why:**

Costs for rate design studies and pilots would be minimal.

**9) Who is empowered to implement this recommendation?**

Legislators, community, environmental and low-income advocates

**10) Is there consensus among the subgroup for this recommendation, or are there differing perspectives? If differing perspectives, what are they?**

Certain aspects of how rate design should be structured is not agreed to by all stakeholders. Some group members believe, for example, that marginal cost appropriately reflect the cost to serve customers and that electrification will drive investment decisions of fixed assets that must be recovered.

**11) What are the most important considerations for achievability and feasibility of this recommendation?**

Broad stakeholder involvement, transparency in data and design, customer education and engagement.

## **IV. Facilitate Siting of Necessary Energy Infrastructure**

**1) Overview of recommendation.**

Rationale: Decarbonizing the power system at acceptable cost using known commercially available technologies will require building substantial amounts of wind and solar generation in Michigan, as well as siting grid-scale storage and some additional transmission. Siting these power system components will require community acceptance in many places in Michigan and based on prior experience may be challenging. This recommendation addresses the need to achieve the necessary siting with community acceptance.

Recommendation: Adopt state policies and programs that will facilitate siting of necessary renewable generation, storage, and transmission sufficient to achieve a clean energy transition of the electric power sector. Specific actions include:

- A. Establish consistent, predictable, and stable taxation and community benefits policies for renewable generation and electricity storage.
- B. Assign lead responsibility to a state organization to facilitate siting through information sharing, development and communication of best practices, and stakeholder engagement.
- C. Enable local zoning and planning and renewable facility developer planning by creating publicly available grid hosting capacity maps (this may also be useful in planning electric vehicle charging infrastructure). Ideally, grid hosting capacity maps would also overlay with renewable resource conditions, existing land use information, environmental considerations, zoning information, and other information that will be useful for siting decisions and community consideration of siting requests.
- D. Engage an advisory group of stakeholders and create a public toolkit of information related to power system siting that will be useful to host communities and establish best practice expectations for all stakeholders.

- E. Develop feasibility studies and siting criteria for battery and non-battery energy storage systems in Michigan.
- F. Evaluate whether off-shore wind siting is needed or warranted to decarbonize Michigan's power sector and if warranted, develop the necessary legal construct and guidelines for such development.

**2) In what timeframe is this recommendation achievable?**

This recommendation is achievable by 2025 and should be implemented within that timeframe to ensure that Michigan has an adequate foundation for siting the renewable generation, storage, and transmission resources that will be needed to decarbonize the electricity grid.

**3) What is the relative magnitude of this recommendation, in terms of GHG emissions reductions?**

Siting is one of several actions that must take place to decarbonize electricity in Michigan. Holistic integrated systems planning, deployment of behind-the-meter resources, and effective rate designs will all help to ensure an efficient electricity grid and reduce the need for large new infrastructure projects. However, even with all of those recommendations, there will likely need to be a large build-out of renewable energy resources, storage, and transmission to achieve the state's climate goals. That new infrastructure will need to be successfully sited somewhere. This recommendation will help to ensure it is sited wisely and with community input. For these reasons, this doesn't necessarily have direct emissions reductions, but is an enabler of reductions.

**4) Describe the potential impacts of this recommendation on environmental justice.**

Environmental justice must be a core consideration of siting energy infrastructure in Michigan. By implementing the sub-actions listed in this recommendation, Michigan has an opportunity to ensure that siting is done in a way that addresses past injustices, does not create new injustices, and ensures equitable allocation of the costs and benefits of energy infrastructure projects.

**5) Describe the potential impacts of this recommendation on labor.**

Building out energy infrastructure will create significant opportunities for Michigan's workforce, but the opportunities may not necessarily be spread evenly across the state. Siting is important because siting constraints will determine where in the state those opportunities occur.

**6) Describe the potential impacts of this recommendation on the environment.**

All energy infrastructure has environmental impacts. Thoughtful siting can help to ensure that negative impacts are minimized and that co-benefits are maximized. For example, solar panels can be planted with pollinator friendly habitat underneath the panels to support local ecosystems and reduce runoff.

**7) Describe the potential impacts of this recommendation on economic development.**

Building new energy infrastructure will create economic development opportunities in Michigan, including for businesses involved in construction, local economic ripple effects from those businesses, and potentially tax benefits for local governments where the infrastructure is being sited. However, as with workforce impacts (see #5 above), the opportunities will be located based on siting constraints.

**8) What are the relative costs of this recommendation? Unknown, or different timeframe – explain why:**

Compared to the costs of energy system infrastructure, the sub-actions under this recommendation are relatively affordable. Moreover, money spent on these actions can help to reduce the costs of building new infrastructure. For example, poorly sited infrastructure may create community pushback that delays construction timelines and increases project costs. Therefore funding to support these actions may create additional value for the State of Michigan.

**9) Who is empowered to implement this recommendation?**

State government, including EGLE, should take the lead in implementing this recommendation. Some components of this recommendation will also need to be implemented by local governments.

**10) Is there consensus among the subgroup for this recommendation, or are there differing perspectives? If differing perspectives, what are they?**

The group was mostly in consensus about the recommended sub-actions. There was some concern expressed that the siting question presumed renewable development rather than evaluating renewables against other options. But the group was otherwise in agreement that the renewable presumption did define the task, and made sense for Michigan.

**11) What are the most important considerations for achievability and feasibility of this recommendation?**

## **V. Evaluate Gas System Regulatory and Policy Options**

**1) Overview of recommendation.**

Rationale: Natural gas used for space heating, water heating, and industrial processes is the primary driver of greenhouse gas emissions from Michigan's residential, commercial, and industrial sectors, which collectively contribute one third of the state's economy-wide greenhouse gas emissions. Achieving the state's goals of economy-wide carbon neutrality by 2050 and net negative GHG emissions thereafter will require significantly reducing emissions from natural gas end uses through a combination of technologies and approaches including, but not limited to, energy efficiency, electrification, and low/no emissions gaseous fuels. Determining the right mix of technologies and approaches to serve Michigan's needs in each sector will require ongoing research and analysis, stakeholder engagement, and learning through action.

Given the importance of natural gas service in Michigan as a cold climate state with a significant industrial sector, the impacts of natural gas use on state greenhouse gas emissions reduction goals, and the effects of climate change on the state, the Governor's Office, EGLE, the legislature, and the Michigan Public Service Commission (MPSC) will likely need to make decisions in the future about how to reduce greenhouse gas emissions from natural gas in a way that balances environmental and health concerns with rates, reliability, safety, and equity.

Many of those decisions will pertain to new ideas and emerging technologies. This presents three challenges:

- First, the State's lawmakers, regulators, and stakeholders will need to become knowledgeable about the different approaches and technologies that can reduce emissions from natural gas end uses in order to assess and determine appropriate utility investments.
- Second, the State will need to have a regulatory framework in place that provides for consideration and evaluation of approaches and technologies that can reduce emissions from natural gas end uses, especially those that may be brought forward by the state's natural gas utilities.
- Third, to the extent the natural gas system may shrink in favor of electrification, the State and the state's gas utilities will need a process to handle a wind-down of the gas system infrastructure while maintaining system safety, affordability and reliability.

The following recommendation aims to address these needs through a series of measures.

Recommendation: The governor should direct EGLE and/or the Michigan Public Service Commission to initiate a staff-run stakeholder group or proceeding to evaluate opportunities and considerations for changes to gas utility regulatory and policy structures needed to support cost-effective and equitable achievement of the state's economywide greenhouse gas reduction goals. This stakeholder group or proceeding should include the following components:

- A. First, conduct a pathways analysis to assess options to achieve net zero greenhouse gas emissions from natural gas production, transmission, distribution, compression, storage, and end uses in a least-cost manner. This should be implemented as part of a broader pathways analysis to achieve Michigan's climate goals, addressing all key economic sectors (power generation, transportation, industry, and agriculture), as their interconnected nature will require consistent assumptions and cross-referencing of outputs. This analysis should include the following:
  - i. An assessment of the strengths and limitations of net zero emissions fuels and technologies, and the costs and implications of various decarbonization pathways for current gas end uses. Fuels and technologies to consider should include, but not be limited to, energy

- efficiency, demand response, electrification, renewable natural gas, hydrogen, and district energy systems.
- ii. An inventory of assets utilized in the production, transmission, and distribution of natural gas in Michigan, to build understanding of the current natural gas system and aid the evaluation of any potential wind-down of the system.
  - iii. Impacts to Michigan's workforce that may occur as a result of reducing emissions from natural gas production, transmission, and distribution .
- B. Second, based on the assessment, identify and implement actions and policy changes that are needed to meet Michigan's greenhouse gas reduction goals with respect to natural gas production, transmission, distribution, compression, storage, and end uses. This should include the following:
- i. Consideration of regulatory measures and frameworks that can support natural gas and electric utility innovation to reduce emissions, including, but not limited to, the following:
    - a. A gas utility emissions reduction planning process, under which gas utilities could submit innovation plans to the MPSC that propose (for MPSC review and approval) investments to reduce greenhouse gas emissions from the natural gas system. This could include measures to maintain affordability, such as spending caps.
    - b. Utility and/or customer facing financial incentives for approaches and technologies that can reduce natural gas system emissions. These could include tax incentives, rebates, loan funds, or regulatory incentives.
    - c. A clean fuel standard, which would require a certain percentage of fuel in a utility's natural gas supply to have a lower carbon intensity than fossil natural gas, and which would put all solutions for reducing natural gas end use emissions on a level playing field.
    - d. Facilitate permitting of utility infrastructure than can aid in achieving greenhouse gas emissions reductions, including seeking "primacy" from EPA on the permitting of CO2 pipelines and storage facilities, which will allow for more local control over permitting decisions and facilitate faster decarbonization in a more cost-effective manner.
    - e. Create liability protection associated with CO2 leaks from underground reservoirs, assuming that a standard set of precautions and controls are appropriately implemented by the reservoir operator.

- f. Policies that support the development and interconnection of facilities supplying lower carbon intensity sources to the natural gas system (e.g., RNG, hydrogen).
- ii. Consideration of policy changes to reduce emissions from natural gas production in Michigan, including the following:
  - a. Recommending to the Legislature that MCL 324.61502 – part of “Act 61” – be amended to strike the following policy language: “It is accordingly the declared policy of the state to protect the interests of its citizens and landowners from unwarranted waste of gas and oil and to foster the development of the industry along the most favorable conditions and with a view to the ultimate recovery of the maximum production of these natural products.”
  - b. Recommending that EGLE begin to enforce the statutory prohibition of oil-gas waste, MCL 324.61504, by stopping a current practice of operators in Michigan’s Antrim Shale, the venting of one million tons per year of produced CO<sub>2</sub> to the atmosphere.
  - c. EGLE and MPSC work with natural gas producers, pipelines and LDCs to develop a mechanism to detect and mitigate methane leaks.
- iii. Consideration of the role of the natural gas system in a decarbonized economy, including whether parts of the system should be decommissioned in favor of electrification. To the extent that parts of the natural gas system will be decommissioned, the State should consider the following:
  - a. Developing and implementing a strategic and orderly process for evaluating the gas distribution system and determining whether, where, and how the system should wind down in order to meet the state’s GHG reduction goals. In the process, the commission should continue to address safety, liability, and reliability.
  - b. Evaluating possible gas system reuse or retrofit options (broadband/fiber optics infrastructure, water infrastructure & transport, use for liquid storage, use for CO<sub>2</sub> transport to storage, use for green long-duration energy storage).
  - c. Securitization or other regulatory or financing measures to reduce the ratepayer and/or utility burden that may result from stranded assets.



- d. Implementing analysis, planning exercises, and pilot programs to effectively engineer the deconstruction of existing fuel system infrastructure and provide for electrification retrofits.
- e. Ensuring that state agencies lead any gas system wind-down process by maintaining granular management of the process inputs and firm control of outputs using in-house expertise.
- f. Ensuring that body of law for the State of Michigan and the structure within and among State agencies and/or departments is functional to facilitate the work of “winding down the gas system.”
- g. Establishing policies and standards for integrity, transparency, and accountability with regard to a gas system wind-down.

**2) In what timeframe is this recommendation achievable?**

The recommended MPSC process should be initiated before 2025, however the changes resulting from the process may take longer.

**3) What is the relative magnitude of this recommendation, in terms of GHG emissions reductions?**

The policy and regulatory changes that would be identified after the pathways analysis have the potential to help Michigan achieve net zero emissions from natural gas production, transmission, distribution, compression, storage, and end uses. Looking at carbon emissions from natural gas end-use combustion in the residential, commercial, industrial, and transportation sectors (excluding natural gas for electricity generation), this recommendation has the potential to reduce up to 39.5 million metric tons of carbon dioxide emissions. This recommendation also has the potential to reduce methane leakage from the natural gas system. Methane doesn't last in the atmosphere as long as carbon dioxide, but it has a much higher warming potential, making it more potent and concerning from climate standpoint.

**4) Describe the potential impacts of this recommendation on environmental justice.**

It is important that this process include the perspectives of environmental justice communities and advocates. Any pathway to achieve net zero greenhouse gas emissions from the natural gas system will likely have environmental justice and equity implications. For example, switching from geologic natural gas to renewable natural gas may reduce greenhouse gas emissions, but may still result in public health concerns with respect to indoor air quality. This can be mitigated with better ventilation in homes, but it should not be ignored. Electrification may also have implications, as serving Michigan's building heating load with electric heat pumps would likely require a significant build out of the electric system to serve the winter heating peak – the siting of the infrastructure should be done carefully and with input from local communities.

Finally, without policy intervention to address affordability, electrification of natural gas end uses could result in a scenario where the fixed costs of the gas system need to be spread out across fewer units of gas sold and/or fewer customers, raising gas rates. In particular, the customers least able to adopt electrification technologies may be stuck with much higher energy bills. This will need to be carefully mitigated.

**5) Describe the potential impacts of this recommendation on labor.**

Any pathway to achieve net zero greenhouse gas emissions from the natural gas system will likely create both challenges and opportunities for Michigan's workforce. The specific impacts will depend on which pathway is ultimately pursued. For example, significant electrification may create new workforce opportunities for workers in the electric sector, but may reduce opportunities for workers in the gas sector. These impacts should be considered as part of the process outlined above. To the extent there will be new workforce opportunities, the state should work to facilitate fair and equitable access to those opportunities.

**6) Describe the potential impacts of this recommendation on the environment.**

The goal of this process is to significantly reduce greenhouse gas emissions. However, all fuels and technologies may have environmental impacts. Significant electrification may require greater land use for renewable energy such as wind and solar. If sited appropriately and with community input, renewables can be sited to minimize environmental impacts and maximize co-benefits, such as pollinator friendly habitat planted under solar panels. Significant development of ne-zero emissions gaseous fuels may also have environmental impacts. Producing green hydrogen for industry would likely have many of the same environmental impacts as electrification, given that wind and solar will be needed to power electrolyzers. Renewable natural gas would have reduced lifecycle GHG emissions, but would still emit some air pollution at the point of combustion.

**7) Describe the potential impacts of this recommendation on economic development.**

The actions resulting from this process will likely create several economic development opportunities. Regardless of the fuels or technologies being deployed, any pathway to achieve net zero emissions from the gas system will require significant investment in research, development, and deployment, including building out new infrastructure.

**8) What are the relative costs of this recommendation? Unknown, or different timeframe – explain why:**

The stakeholder engagement process outlined above would be very inexpensive in comparison to magnitude of investment that will be needed to significantly reduce emissions from the industrial sector. A year-long stakeholder engagement process could cost around \$300,000 to \$500,000, though the costs may vary depending on the process design and extent of modeling required.

Achieving net zero emissions from the gas system will be expensive, and the costs will depend on a number of factors, including the mix of fuels and technologies deployed, policy favorability for those fuels and technologies, competition for net zero emissions fuels from other sectors (such as transportation), and the relative cost of conventional natural gas, which would impact the incremental cost of net zero emissions options. Recent modeling conducted in Minnesota found that, by 2050, achieving net zero emissions from natural gas end uses in that state would incur an incremental cost of \$9 billion to \$20 billion annually (in nominal dollars).

Source (figure 22 on page 47): <https://e21initiative.org/wp-content/uploads/2021/07/Decarbonizing-NG-End-Uses-Stakeholder-Process-Summary.pdf>

**9) Who is empowered to implement this recommendation?**

State Government – Executive

Michigan Public Service Commission

**10) Is there consensus among the subgroup for this recommendation, or are there differing perspectives? If differing perspectives, what are they?**

There was broad support, if not consensus, amongst the workgroup for conducting the pathways analysis described in this recommendation. There was also broad support for the idea that the pathways analysis should inform the development of policies and frameworks to reduce greenhouse gas emissions from the gas system. However, there is debate about which policies and frameworks should be considered, including a variety of perspectives on whether and how a wind down of the natural gas system should be considered. There is also debate about the specific fuels and technologies that should be considered to achieve net zero emissions. Importantly, the process that is recommended could provide a venue for stakeholders to continue discussing these perspectives.

**11) What are the most important considerations for achievability and feasibility of this recommendation?**

The pathways analysis is vital to this recommendation. In order for the modeling results to be trusted by stakeholders, there should be an effort to build agreement on the modeling inputs and assumptions so that stakeholders can discuss the meaning of the results, rather than discuss whether the results are accurate or not.

# MI HEALTHY CLIMATE PLAN



MICHIGAN DEPARTMENT OF  
ENVIRONMENT, GREAT LAKES, AND ENERGY

APRIL 2022



MICHIGAN DEPARTMENT OF  
ENVIRONMENT, GREAT LAKES, AND ENERGY

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## LETTER FROM EGLE DIRECTOR



Dear fellow Michigan residents:

I am proud to present the MI Healthy Climate Plan, with thanks to Governor Gretchen Whitmer for trusting the Michigan Department of Environment, Great Lakes, and Energy to lead this work and deep appreciation for the hundreds of Michiganders who contributed to it over the past year through thousands of hours of research, reflection, and conversation.

This plan lays out a broad vision for fulfilling the governor's fall 2020 commitment for Michigan to achieve 100% economy-wide carbon neutrality by midcentury – the global science-based benchmark for reducing greenhouse gas emissions to avoid the most devastating and costly impacts of climate change.

As its name suggests, this is a uniquely Michigan plan. It was shaped by a multitude of Michiganders with varied perspectives on climate change. We heard from environmental justice, public transit, local food, and climate action advocates; an array of business and labor leaders; academic experts and local government officials; and concerned residents of all political persuasions and walks of life. I firmly believe conversation leads to better outcomes. In this case, it has produced a bold plan that a broad cross-section of Michiganders can rally around.

This Plan is also rooted in what makes our state special. No state is better positioned than Michigan to advance equity, create good-paying jobs, increase economic competitiveness, and improve quality of life in pursuing carbon neutrality – thanks to our unmatched freshwater resources and heritage as a global manufacturing innovator, diverse agricultural producer, world-class outdoor recreation hub, and home to talented people and vibrant communities.

Finally, the responsibility for implementing this Plan and refining it over time is ours. All 10 million of us have big parts to play in decarbonizing our economy – from the governor and state lawmakers who will make the necessary state policy changes and budgetary decisions to the workers, business leaders, and entrepreneurs who will turn cutting edge climate solutions into high-quality jobs and economic prosperity; the community leaders and advocates who will ensure this work reaches every corner of the state and benefits every Michigan family; and each of us as individuals and consumers who will take myriad actions in our daily lives.

It is essential that we act now to greatly accelerate the decarbonization of Michigan's economy, building on the recent progress Michigan has made thanks to our public and private sector leaders. While some solutions to achieve a 100% decarbonized economy that delivers good jobs and justice are still on the drawing board, most are well known to us and awaiting our commitment to getting the job done and equitably sharing the burdens and benefits.

Fortunately, we have the resources to demonstrate that commitment and kickstart progress. Governor Whitmer's 2023 state budget recommendation includes over \$500,000,000 for climate, clean energy, and mobility initiatives. And the state is committed to fully leveraging the current dramatic influx of federal dollars to move Michigan closer to our decarbonization goals.

In other words, we have a commitment, a plan, and a financial platform. We have what we need, so let's get to work.

A handwritten signature in blue ink, appearing to read 'Liesl Eichler Clark', written over a faint, larger blue ink signature.

Liesl Eichler Clark, Director  
Michigan Department of Environment, Great Lakes, and Energy

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## EXECUTIVE SUMMARY

The real and costly impacts of the climate crisis are irrefutable and that was especially obvious on the ground in Michigan during 2021. Severe, climate-induced weather events over the summer caused more than one million Michiganders to lose power, some for a week or more. Southeast Michigan was hit by intense rain, causing widespread floods and sewer backups. All this came on the backend of a decade in which our state has experienced massive flooding and dam failures, high water levels and erosion that destroyed public and private property, major crop failures from erratic spring temperatures, and three polar vortexes that challenged Michigan families to keep the heat on.

Sadly, Michigan is not alone. We all remember Texas freezing over after unprecedented cold and ice storms in February 2021, taking lives, freezing pipes, and causing historic damage.

Meanwhile, California was ablaze, hit by twice as many wildfires as the previous record year. A “heat dome” that settled over the Pacific Northwest in late June broke the previous record temperature by more than 10 degrees.

Globally, the seven warmest years in recorded history have occurred since 2015, a trend the United Nations’ Intergovernmental Panel on Climate Change has called “a code red for humanity.”

If we do not act aggressively to reduce greenhouse gas (GHG) emissions, these changes will only intensify, and the impacts will become more challenging, dangerous, and expensive for Michigan residents. It is imperative that we reduce emissions as quickly as possible and simultaneously prepare for the changes we cannot prevent.





The good news is we have made progress in recent years in reducing our GHG emissions. In the process, we have learned that aggressive action on climate change presents a variety of significant opportunities to better the lives of all Michiganders, including offering immediate opportunities to **reduce costs** and create **good-paying jobs for working families**.

Governor Whitmer has taken bold action to dramatically accelerate Michigan's progress down that promising path, including committing Michigan to economy-wide carbon neutrality no later than 2050 with aggressive interim targets on the way to midcentury and net negative GHG emissions thereafter. To achieve these ambitious goals, she charged the Michigan Department of Environment, Great Lakes, and Energy's (EGLE) Office of Climate and Energy with developing the *MI Healthy Climate Plan* (Plan). ([See Introduction](#))

**MICHIGAN - one of only 14 states with bold economy-wide goals**

- ✓ Reduce GHG emissions 28% below 2005 levels by 2025 and 52% by 2030
- ✓ Achieve economy-wide carbon neutrality by 2050
- ✓ Maintain net negative GHG emissions thereafter

## OBJECTIVES



Mitigate the worst impacts of climate change



Spur economic development and create good-paying jobs



Capture economic development and create good-paying jobs



Protect and improve the health of Michiganders

## OBJECTIVES OF THE MI HEALTHY CLIMATE PLAN



Position Michigan as a leader in climate action



Protect our natural resources and wildlife



Make Michigan energy independent



Address environmental injustices

The Plan strongly emphasizes environmental justice to ensure Michigan’s climate strategies uplift every portion of the state, including individuals and communities that have borne the brunt of climate impacts and are at the greatest risk of being left behind in the transition ahead. It also spotlights decarbonization strategies that will yield significant health, economic, and other benefits. (See [Why Climate Action Matters for Michigan](#)).

The Plan is meant to identify what needs to happen for Michigan to reach carbon neutrality by 2050 with a prioritization on actions from now until 2030. It focuses most heavily on the areas where the biggest, most rapid gains in GHG reductions can be made – energy, transportation, and buildings. The Plan’s full complement of recommendations are detailed in the [Roadmap to 2030](#) section. The following briefly summarizes the highlights across the six categories the Plan uses to group the climate actions needed to achieve our goals.

**Commit to Environmental Justice and Pursue a Just Transition:** Ensure that at least 40 percent of state funding for climate-related and water infrastructure initiatives benefit Michigan’s disadvantaged communities (in line with the federal government’s Justice40 guidelines for federal funding); that Justice40 is developed in partnership with leaders in disadvantaged communities; and that Michigan emphasizes a just transition for all workers through proactive engagement, job training, and workforce development.

**Clean the Electric Grid:** Generate 60 percent of the state’s electricity from renewable resources and phase out remaining coal-fired power plants by 2030. Limit energy burden from powering and heating homes to not more than 6 percent of annual income for low-income households.

**Electrify Vehicles and Increase Public Transit:** Build the infrastructure necessary to support 2 million electric vehicles on Michigan roads by 2030. Increase access to clean transportation options – including public transit – by 15 percent each year.

**Repair and Decarbonize Homes and Businesses:** Reduce emissions related to heating Michigan homes and businesses by 17 percent by 2030. Increase investments in repairing and improving buildings to reduce costs for working families and small businesses.

**Drive Clean Innovation in Industry:** Encourage clean innovation hubs where private enterprises strategically co-locate and collaborate to develop and deploy new, cleaner manufacturing technologies and conduct research and development to reduce emissions from hard to decarbonize industries. Triple Michigan’s recycling rate to 45 percent and cut food waste in half by 2030.

**Protect Michigan’s Land and Water:** Protect 30 percent of Michigan’s land and water by 2030 to naturally capture GHG emissions, maintain and improve access to recreational opportunities for all Michiganders, and protect biodiversity. Leverage innovative strategies to support climate-smart agriculture.

The Plan's comprehensive set of policy recommendations in these areas will help reduce GHG emissions at the scale and pace necessary to reach our interim goal of reducing GHG emissions 52% by 2030. However, they do not go far enough on their own. Additional policy changes and actions in every sector will be necessary to get all the way to that target. That is why we must continue to evaluate and update strategies (and this Plan) and seek new emissions-reduction pathways that will spur a self-reinforcing cycle and more fully unleash Michigan ingenuity.

Beyond 2030, the steps necessary to make Michigan's economy carbon neutral by 2050 are no less urgent. In many cases, the actions necessary to fully achieve this goal over the next 28 years will require substantial efforts in the sectors of our economy that are hardest to decarbonize, including industry, buildings and housing, and agriculture. The Plan takes a balanced approach to these issues, identifying the actions we can take today to make real progress between now and 2030, while also immediately digging into the hard work of identifying strategies to get us the rest of the way to carbon neutrality by 2050. To achieve our goals, we must also avoid actions between now and 2030 that make it more difficult to reach carbon neutrality.

It is also important to note that this Plan is a climate mitigation and greenhouse gas reduction plan, not a comprehensive plan to adapt and become resilient to the effects of climate change. That said, as we work toward our 2030 and 2050 goals, the State will support residents and communities in adapting to the climate impacts we are already facing, especially those in historically disadvantaged and underserved communities. Additionally, mitigation and adaptation are not mutually exclusive – their actions often overlap and benefit each other. Still, while there are climate adaptation considerations in this document, they do not constitute a holistic climate adaptation strategy for Michigan.

Concerted action by all Michiganders will be required to achieve the steep reductions in GHG emissions our state needs to achieve its goals. Fortunately, our communities, businesses, and institutions have already stepped up and created strong momentum for us to build upon. As described further below, the State of Michigan is also leading by example with Governor Whitmer directing state departments to use all the tools at their disposal to reduce GHG emissions in their operations and otherwise act on climate. (See [Leading by Example in State Government](#))

While the objectives detailed in the rest of this Plan are ambitious—and in some cases daunting—it is important to recognize that our journey to carbon neutrality has already begun thanks to the leadership, creativity, and ingenuity of Michiganders across our state.



## INTRODUCTION

### GOVERNOR WHITMER'S COMMITMENTS



Recognizing the urgency of the crisis and the opportunities to build a better future for Michigan as we reduce our GHG emissions (see [Why Climate Action Matters for Michigan](#)), Governor Gretchen Whitmer has taken bold and sustained action on climate change since taking office.

In September 2020, she signed [Executive Directive 2020-10](#), which committed Michigan to a goal of achieving economy-wide carbon neutrality no later than 2050 and maintaining net negative greenhouse gas emissions (GHG) thereafter. [Carbon neutrality](#) means that any carbon dioxide released into the atmosphere is balanced by an equivalent amount being removed. She also reaffirmed the goals in Executive Directive 2019-12, which committed Michigan to pursue at least a 26-28 percent reduction below 2005 levels in GHG emissions by 2025. In addition to the goals set by these directives, Michigan joined 24 other states and Puerto Rico – under the umbrella of the U.S. Climate Alliance – in committing to an interim goal of a 52 percent GHG reduction by 2030.

Executive Directive 2020-10 charged EGLE, through its Office of Climate and Energy (OCE), with developing the *MI Healthy Climate Plan* to serve as this state's action plan to reduce GHG emissions and transition toward economy-wide carbon neutrality with a focus on solutions that support communities disproportionately impacted by the changing climate.

### Michigan's Commitment

In addition to leadership from state government, this progress has been driven – and will continue to be driven – by the actions and commitments of Michigan's communities, businesses, and institutions, including, but not limited to, the examples below.

**Leading communities:** At least [16 Michigan communities](#), ranging from the City of Ann Arbor to Shelby Township, have set goals to be carbon neutral or to reach 100 percent renewable energy by 2050.

**Tribal leadership:** The [Sault Ste. Marie Tribe of Chippewa Indians](#) has a net-zero energy goal and aims to reduce greenhouse gas emissions by four percent per year.

**Our largest universities:** The [University of Michigan](#) committed to eliminate both direct emissions and emissions from purchased energy between 2025 and 2040. [Michigan State University](#) committed to carbon neutrality by 2050 with interim reduction goals.

**Homegrown businesses:** [Steelcase](#) has achieved carbon neutrality and has set a target to become carbon negative by 2030. [Whirlpool](#) set a net-zero emissions target in its plants and operations by 2030. [Dow](#) set a target of being carbon neutral by 2050. [General Motors](#) (GM) set a goal of carbon neutrality in its global products and operations by 2040. [Ford Motor Company](#) set a goal of carbon neutrality by 2050 and committed to powering its manufacturing plants with 100 percent locally sourced renewable energy by 2035. And many more Michigan businesses – large and small – are stepping up.

**Our largest utilities:** [Consumers Energy](#) set a goal of net-zero carbon emissions by 2040. [DTE Energy](#) set a goal to achieve net-zero carbon emissions by 2050 with interim reductions targets.



## A CLIMATE PLAN SHAPED BY MICHIGAN RESIDENTS

The Plan was developed by EGLE with input from hundreds of Michigan residents. To serve as the primary venue for gathering and channeling that input, Governor Whitmer created the Council on Climate Solutions through [Executive Order 2020-182](#).

The [Council](#) consists of 14 Michigan residents appointed by the governor to represent a range of sectors, experiences, and expertise relevant to climate issues. Additionally, the Council includes the directors (or their designees) of EGLE and the Michigan Departments of Agriculture and Rural Development (MDARD), Labor and Economic Opportunity (LEO), Michigan Economic Development Corporation (MEDC), Natural Resources (DNR), Transportation (MDOT), and Health and Human Services (DHHS), as well as the State Treasurer and the Chair of the Michigan Public Service Commission (MPSC).

The Council met 14 times in 2021 to develop a common knowledge base on the climate challenge and discuss the content and recommendations laid out in this Plan and its appendices. To dig deeper and tap broader expertise across Michigan in key areas, five topical workgroups were formed to support the Council:



Energy Production, Transmission,  
Distribution, and Storage



Transportation and Mobility



Buildings and Housing



Natural and Working Lands and  
Forest Products



Energy Intensive Industries



In addition to the above workgroups, an internal group led by EGLE staff provided recommendations on decarbonization related to materials management.

Hundreds of Michiganders participated in these come-one-come-all workgroups, the membership of which was open to the public. Each was co-chaired by a State of Michigan official and a private-sector resident with subject-matter expertise in the relevant field. These workgroups met periodically through much of 2021 and presented their recommendations to the full Council in the closing months of the year. Listening sessions were then conducted to receive public input on those recommendations (a complete set of which is provided in the appendices).

In 2022, EGLE released a draft of this Plan for public feedback, welcoming written comments and creating forums for the public to engage and comment on the plan. After overwhelming interest, EGLE extended the timeline for input. In addition to public forums, EGLE facilitated consultation with tribal governments and hosted meetings with Council and workgroup members, key stakeholders, and the Michigan Advisory Council on Environmental Justice (MAC-EJ).



# WHY CLIMATE ACTION MATTERS FOR MICHIGAN

## MICHIGAN IS FEELING THE IMPACTS OF CLIMATE CHANGE

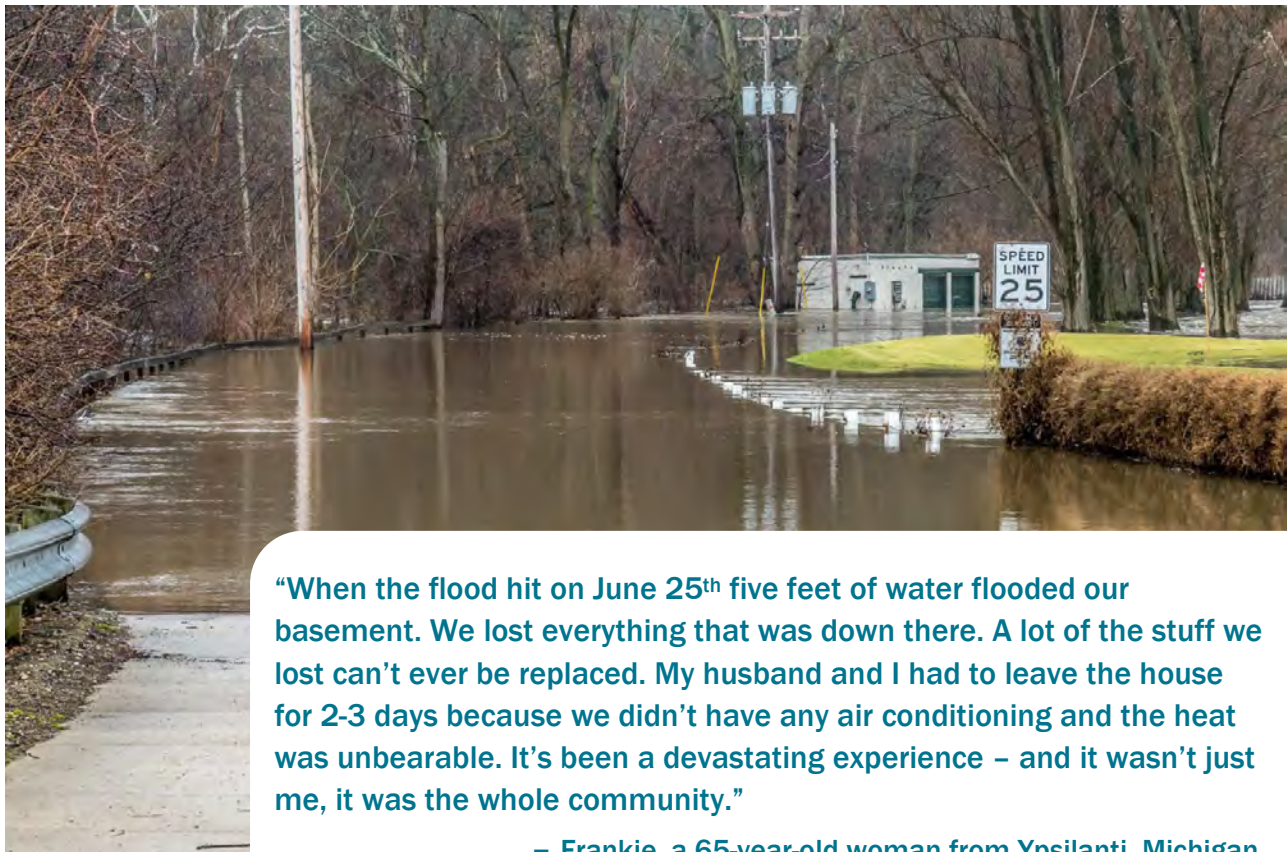
*Immediate, aggressive action on climate change ensures that Michiganders – present and future – can thrive in Michigan.*

In just the last three years, Michigan has felt the real impacts of climate change. The state has faced a polar vortex that forced residents to come together to keep the heat on, high lake levels that crumbled personal property and public infrastructure, record flooding that caused sewers to back up into homes, increased instances of disease-carrying insects, toxic algal blooms that put our waters in danger, the temporary closure of businesses that rely on seasonal consistency, the breaking of dams that led to the evacuation of a community, and week-long power outages.

Historically stable patterns are changing rapidly in unpredictable ways. Compared to 1900, Michigan is [almost 3 degrees warmer](#) and gets around five more inches of rain per year.

### Frequent and intense storms

Michigan is experiencing historic levels of rain and intense storms. A continuation of extreme rain will lead to more property loss and infrastructure failures, an increase in the likelihood of contamination, bacteria, algal blooms in water supplies, and the risk of contracting waterborne diseases like Legionnaire's. The state has also seen extreme changes in Great Lakes water levels.



**“When the flood hit on June 25<sup>th</sup> five feet of water flooded our basement. We lost everything that was down there. A lot of the stuff we lost can’t ever be replaced. My husband and I had to leave the house for 2-3 days because we didn’t have any air conditioning and the heat was unbearable. It’s been a devastating experience – and it wasn’t just me, it was the whole community.”**

**– Frankie, a 65-year-old woman from Ypsilanti, Michigan.**

## Rapid temperature changes

Michigan summers are becoming hotter and drier. The latest science suggests that summers in Detroit in 2100 will feel like [summers in Dallas do now](#). Extreme heat will lead to increased hospitalizations due to heat exhaustion and heatstroke, wildlife loss from habitat changes, and increased levels of mosquito and tick populations that carry diseases like West Nile Virus and Lyme Disease. As with intense rains, high heat can damage infrastructure and personal property. Michigan is already seeing roads and sidewalks buckle and break from rising temperatures. On the other side of the calendar, Michigan winters are becoming more unpredictable. In the last 10 years, the state has experienced three polar vortexes leading to irregular cold blasts.

Along with more severe extremes, uncertainty in temperatures has also presented newfound challenges, especially for seasonal activities and industries like farming, hiking, camping, boating, skiing, snowmobiling, and ice fishing. This uncertainty was especially prominent in March 2012 when the state experienced a [record-breaking crop loss event](#) when temperatures hit over 80 degrees causing Michigan cherry trees to bloom, only for the crop to be almost entirely lost when temperatures dipped back below freezing in April.



**“In 2012, Michigan lost over 90% of its tart cherry crop because of erratically warm weather that fooled our cherry trees into blossoming while in frost season. Michigan’s agriculture relies on relatively predictable, stable weather conditions. As the climate changes, we have to operate with increasing uncertainty. Some farmers have been forced to import cherries to make up for the losses, make expensive updates, or just leave the industry. Our industry has a rich, proud history in Michigan rooted in its soil, built by its waters, but now those same natural forces are having devastating impacts on our bottom line.”**

**– Bob Sutherland, President of Cherry Republic**

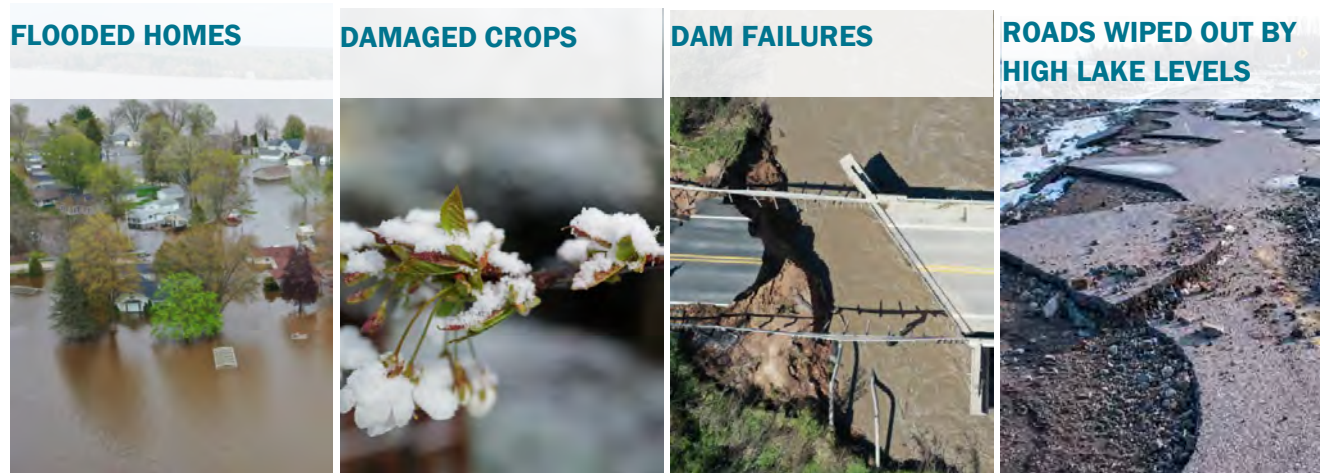


If we don't act aggressively to reduce GHGs, these impacts will only intensify and become more challenging and expensive for Michigan residents. It is imperative that we reduce emissions as quickly as possible and simultaneously prepare for the changes we cannot prevent.

### Importance of adaptation

The MI Healthy Climate Plan is a climate mitigation and greenhouse gas reduction plan, not a comprehensive plan to adapt and become resilient to the effects of climate change. That being said, Michigan families are already feeling the impacts of climate change – with the most vulnerable being hit hardest. Governor Whitmer and the State of Michigan are committed to continuing to support communities as they prepare for and adapt to climate change. This will be done through regular engagement and communication, the sharing of tools and best practices, and a commitment to robust emergency response protocols in the event of a disaster.

The State is also working to make state-owned infrastructure more resilient and is providing funding and guidance to communities to help them do the same. Mitigation and adaptation are not mutually exclusive. In fact, combining the two is essential. According to the [IPCC's most recent report on impacts, adaptation, and vulnerability](#), adaptation measures become less effective the more the planet warms, and mitigation efforts that do not anticipate future conditions are less effective. We must adapt to the existing impacts of climate change as we work to decarbonize our economy.



## ACTION IS AN OPPORTUNITY TO IMPROVE HEALTH OUTCOMES

*Protecting our public health, air, and water by reducing our reliance on fossil fuel technologies like coal-fired power plants.*

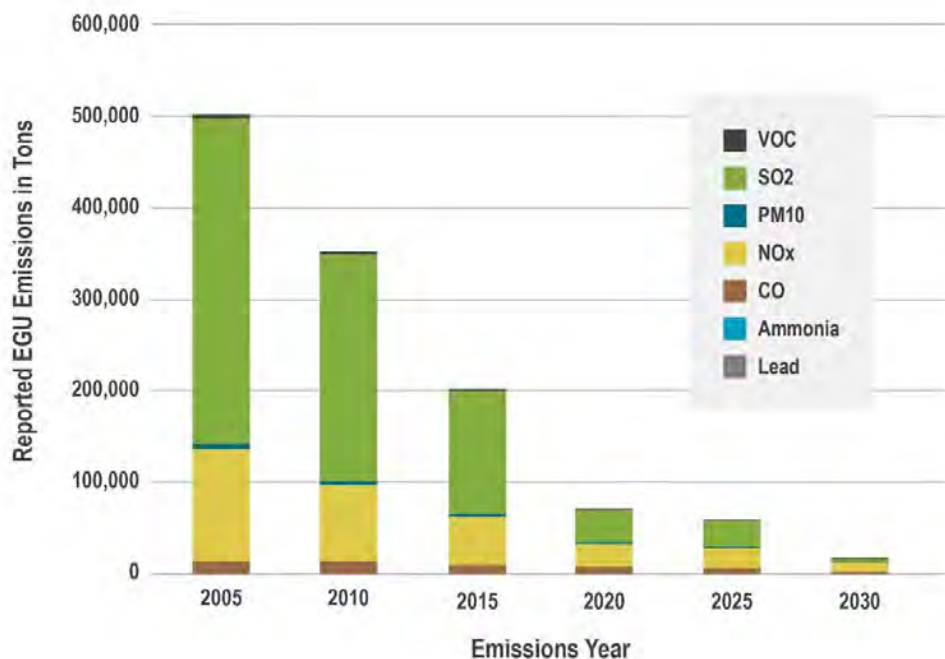
As Michigan implements the strategies in the Plan to reduce GHG emissions, levels of other harmful pollutants in our environment will continue to drop in tandem. That's why determined action to achieve carbon neutrality is an opportunity to dramatically improve public health outcomes, reduce health costs, and avoid lost wages from trips to the doctor, emergency room, or worse. This is especially true for families and communities historically impacted by pollution.

### Easier to breathe

To take the example of one air pollutant, [studies](#) have found that breathing in particle pollution—of which coal-fired power plants are a major source – leads to decreased lung function, increased levels of asthma, exacerbated respiratory symptoms such as coughing or difficulty breathing, and even premature death in people with heart or lung disease. According to state and national data, Michigan's particulate matter pollution from power plants has dropped 73 percent since 2005 as the state has transitioned away from coal-fired power to cleaner energy sources.

As Graph A shows, closing coal-fired power plants and transitioning to cleaner energy sources has spurred similar emissions reductions in Michigan across the five common air pollutants for which the U.S. Environmental Protection Agency sets National Ambient Air Quality Standards (because of their respiratory, cardiovascular, and other harms). Emissions of those pollutants from energy generation in Michigan has dropped 85 percent since 2005. With the closure of our state's remaining coal-fired power plants by 2030, that figure is expected to rise to 96.4 percent. In addition, estimated PM2.5 emissions from electric generating utilities declined from 2,302 tons in 2005 to 1,349 tons in 2020.

### Criteria Pollutants from EGUs



All data is in estimated tons of emission in 2017

Sources: Michigan Air Emissions Reporting System (MAERS) and the EPA's triennial National Emissions Inventory (NEI)

Demonstrating how this Plan’s primary focus on decarbonizing Michigan’s energy production, transportation, and buildings will drive public health benefits, Table A shows the extent to which each of those sectors contribute to emissions of those five common air pollutants.

The transportation sector is currently the largest source of those pollutants in Michigan (Table A). Federal auto emission standards have and will continue to reduce pollution from internal combustion engines. In fact, total emissions dropped around 20 percent between 2014 and 2017. However, we can accelerate those reductions by electrifying our transportation sector. As Michigan residents transition to electric vehicles, we can expect greater improvements in air quality and a decline in related health problems. Better public transit and an increased availability of walking and biking opportunities will also reduce harmful emissions and give residents better opportunities for exercise and enjoyment of Michigan’s recreational amenities.

This is particularly important in areas disproportionately impacted by pollution from the concentration of major transportation corridors there. As Michigan works to decarbonize our transportation sector according to this Plan, state and local transportation planning processes should more fully account for health impacts and emphasize solutions that will accelerate the reduction in transportation-related air pollution.

### Emissions by Pollutant

| Pollutant                  | Electricity<br>Generating Units | Residential<br>Heating | Transportation |            |           |
|----------------------------|---------------------------------|------------------------|----------------|------------|-----------|
|                            |                                 |                        | Heavy Duty     | Light Duty | Refueling |
| Ammonia                    | 98                              | 3,592                  | 220            | 2,830      |           |
| Carbon Monoxide            | 10,287                          | 82,401                 | 38,133         | 641,545    |           |
| Nitrogen Oxides            | 38,704                          | 18,053                 | 39,332         | 66,297     |           |
| PM10 Primary               | 1,134                           | 10,560                 | 4,095          | 4,919      |           |
| Sulfur Dioxide             | 66,296                          | 485                    | 106            | 533        |           |
| Volatile Organic Compounds | 971                             | 11,310                 | 4,342          | 52,992     | 4,456     |

All data is in estimated tons of emission in 2017.

Sources: Michigan Air Emissions Reporting System (MAERS) and the EPA’s triennial National Emissions Inventory (NEI)



While improved air quality is the most direct and widely recognized link between reduced GHG emissions and improved public health, Michigan’s pursuit of carbon neutrality can also benefit our land and water. To take one example, Michigan’s more than two dozen coal ash landfills are another legacy of our state’s historic coal-fired power production. Located close to current and former plants—and in some cases residential areas—these landfills have a history of leaking into underlying aquifers that residents rely on for drinking water. Our transition away from reliance on coal-fired power production will help avoid this contamination in the future.

Finally, we must recognize that climate change is already—and will continue to—have significant public health consequences. Power outages, extreme heat events, exposure to bacteria during sewer backups, and other such climate-related impacts harm Michigan families. Avoiding the most severe such consequences by reducing our GHG emissions as rapidly as possible will help Michigan avoid costly and devastating health outcomes to the greatest extent possible.

In short, decarbonizing Michigan’s economy is a powerful strategy for improving the health and well-being of our 10 million current residents and the generations to come.



**“The [Midland] flood in 2020 had great impact on those with diabetes in this area. We had patients that lost homes or were living outside of their home for a long time after the flood. This led to issues with refrigeration for their insulin and obtaining supplies for their insulin pump because they had no address for their durable medical equipment company to ship their diabetes supplies to.”**

**– Erin, RN, CDCES, Diabetes Center Manager,  
MyMichigan Medical Center, Midland**

## ACTION IS AN OPPORTUNITY TO RIGHT ENVIRONMENTAL INJUSTICES

*Addressing historical harms, prioritizing environmental justice, and creating equitable opportunities for all Michigan residents.*

The State of Michigan should be a place where everyone, no matter their zip code or what is in their wallet, should have the opportunity to thrive – to meet their basic needs, enjoy the dignity of good work, and live in a healthy community with access to affordable housing, water, heat, power, and transportation. Unfortunately, this has not always been the case, particularly for Black, brown, indigenous, rural, and low-income people.

Environmental justice communities are most often communities of color and/or low-income

*The State of Michigan defines environmental justice as the equitable treatment and meaningful involvement of all people, regardless of race, color, national origin, ability, or income in the development and application of laws, regulations, and policies that affect the environment, as well as the places people live, work, play, worship, and learn.*

communities. In addition to facing disproportionate impacts from environmental harms, they generally have been excluded from the opportunities enjoyed by most of society and left behind during major historic economic shifts like our current transition to carbon neutrality.



Environmental injustices are part of a long history of race-based discrimination rooted in the sustained actions, behaviors, and attitudes of institutions and individuals and encoded in our laws at every level. As a result of this structural racial discrimination, environmental justice communities disproportionately neighbor highways, power plants, factories, and other facilities that release pollution into the air and water. Exposure to this pollution over time leads to health issues and lower quality of life. These communities also tend to enjoy fewer trees and lack access to green spaces and other quality outdoor recreation amenities.

Environmental justice considerations are a key component of equitable climate action and will continue to be a priority for the state as it works to eliminate racial disparities impacting the health and well-being of Michiganders. Recognizing that bringing communities of color off the frontlines of the climate crisis and ensuring that they will be full beneficiaries of a carbon neutral economy, Governor Whitmer called on those developing the MI Healthy Climate Plan to design and recommend decarbonization strategies that will prioritize and advance equity and environmental justice. The transition to a carbon neutral economy has the potential to help alleviate existing environmental injustices, address historical harms, and create new opportunities for Michiganders.

## Disproportionate impacts

While Michiganders have relied for generations on the burning of fossil fuels for everything from driving to work to cooking dinner and turning on the lights, many of Michigan's most disadvantaged communities and communities of color have faced the brunt of the environmental and other impacts of an economy based on fossil fuels.

In the electricity sector, high-emitting power generation facilities and related fossil-fuel infrastructure are often located in low-income communities and communities of color. Meanwhile, in Michigan, households with an income below the Federal Poverty Line spend [18 percent of their income on energy](#), compared to an average of 3 percent for the overall population.

In the transportation sector, high-emitting transportation corridors often run right through low-income communities and communities of color, splitting historic neighborhoods in two, [burdening them with higher pollution, and otherwise undermining their quality of life](#).

In homes and businesses, many disadvantaged communities live and work in subpar buildings, face higher energy burden, and are subject to health-related impacts from natural gas appliances, all while lacking access to the investments in energy efficiency and onsite renewable energy seen in other communities.



In the industrial sector, low-income communities and communities of color often endure the environmental and other harms of life on the fence lines of heavy industrial facilities.

Michigan recognizes that tribal nations have also faced disproportionate burdens in our fossil fuel economy and are especially vulnerable to the impacts of climate change because of their deep ties to the land and reliance on hunting, fishing, and gathering. Oil spills and other such contamination have impacted resources like wild rice. The changing climate threatens the sustainability of the Great Lakes fishery which tribal fishers rely upon to earn a living and feed their families. Many cultural practices and traditions require access to species, like the maple tree, that are put at risk by climate change. Michigan's climate strategies and actions must honor, embrace, benefit, and not interfere with the cultural heritage and treaty rights of federally recognized tribal nations in Michigan and preserve the fragile balance of the Great Lakes ecosystem at the heart of that heritage and those rights.





### Just transition

As Michigan transitions away from fossil fuels and traditional carbon heavy industries, it is critical to prepare our workforce for the new opportunities of a carbon neutral economy and ensure all Michigan families have access to those opportunities, particularly those who have not enjoyed equitable access in the past. To ensure our transition to carbon neutrality is just—and avoid responding to climate change in a way that reinforces challenges that historically disadvantaged communities have faced—we need to proactively and intentionally plan for equity and environmental justice. During the transition to a carbon neutral economy, Michigan's most vulnerable communities must be prioritized. The transition to a carbon neutral Michigan needs to happen as fast as possible without leaving anyone behind.

**In response to a 100-year rain event, the Macomb County Health Department surveyed homes.**

“The responses to our post-flood survey allowed us to see the impact socioeconomic factors have on our population's health. We found it concerning that low-income households (37%) were more than twice as likely to report a decline in their health status than high income households (16%). This has provided an opportunity to focus our messaging and community engagement activities going forward to help us better prepare for future emergencies.”

Tom, Environmental Health Services Division Director, Macomb County Health Department

## ACTION IS AN ECONOMIC OPPORTUNITY FOR MICHIGAN

*Creating good paying jobs for Michigan families, increasing our state's economic competitiveness, and lowering costs as we pursue carbon neutrality.*

Climate change is already resulting in economic costs to families and businesses across the state, but strategic and aggressive climate action also presents immediate and long-term opportunities to create economic growth, support good-paying union jobs, and lower costs for working families. Immediate and sustained action on climate is also necessary for Michigan to remain globally competitive in the decades ahead. The transition to a carbon neutral Michigan needs to happen as fast as possible without leaving anyone behind.

### Economic opportunities

Businesses are increasingly focused on climate and are looking to invest and locate in states that embrace clean energy, advanced manufacturing, and the next generation of transportation. If the State acts aggressively on climate and builds on Michigan's strengths in manufacturing and the automotive sector, we can ensure that homegrown companies stay in Michigan and that the state is more attractive to new economic development opportunities.

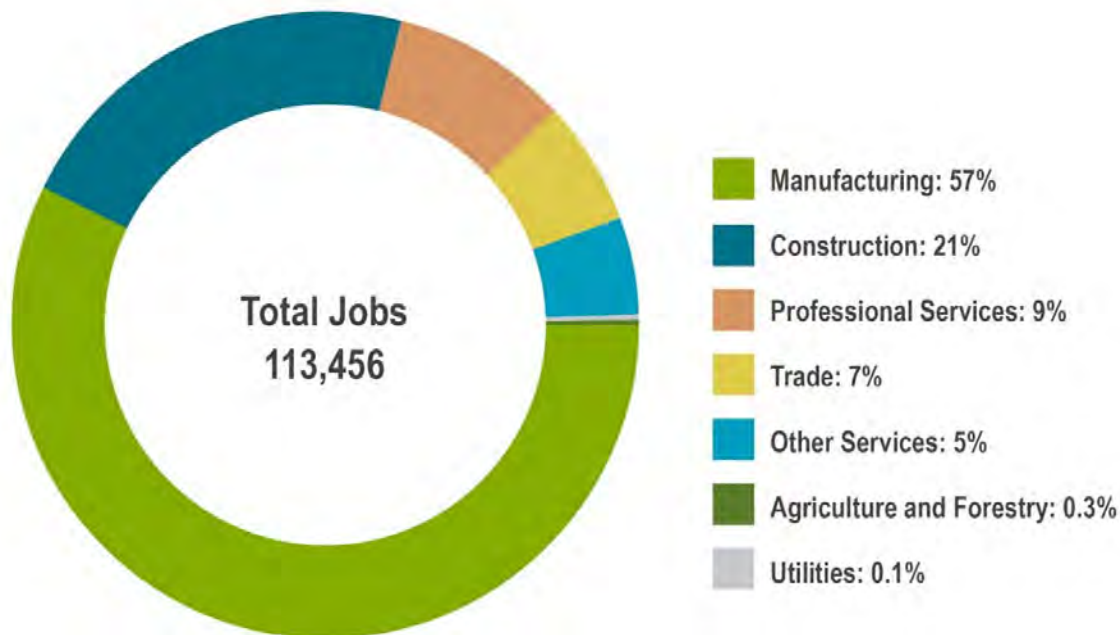


In 2021, Michigan was ranked as a [top 3 state](#) for sustainable development. Over the past three years, according to the Michigan Economic Development Corporation, Michigan has received more than \$16 billion in private investment from mobility and automotive companies. In early 2022, GM announced the company's largest ever investment—a total of [\\$7 billion](#) to develop a new battery factory in the Lansing area and convert an existing factory in Orion Township to electric pickups. This major stake in making Michigan an electrified transportation leader will create 4,000 new jobs and retain another 1,000 existing ones in our state. Michigan has also seen significant investments in clean energy projects with more than [\\$5 billion](#) worth of renewable energy projects coming online since the passage of the state's clean energy law in 2008.



## Good-paying jobs

Michigan is home to over 113,000 clean energy jobs in every region of Michigan with the majority in manufacturing (57 percent) and construction (21.7 percent). Showing its resilience and staying power, [Michigan's clean energy industry](#) rebounded faster than the state's overall economy following the initial onset of the COVID-19 pandemic.



The largest number of clean energy jobs in Michigan are in energy efficiency, ranging from HVAC installation to advanced materials manufacturing. The fastest-growing industry is advanced transportation, which employs more than 24,000 Michiganders. Over two-thirds of Michigan's clean energy jobs are with small businesses employing less than 20 workers. Clean energy jobs [pay up to 25 percent more](#) than the national median wage and are more likely to be unionized and come with health care and retirement benefits than the rest of the private sector. Many of these jobs do not require college degrees. Growing our clean energy workforce, connecting opportunities to the Michiganders who need them most, and providing workers the training and skills that they need to succeed will take sustained, deliberate action from the State and the business community.

**"The transition to electric vehicles is a big deal for union workers, union electrical contractors, businesses, and working families. As a union journeyman, I've worked to provide safe, reliable electrical systems for communities and homeowners, but I am so excited about the new opportunity to install and provide service for electric vehicle charging stations and be a part of this transition. This transition is critical to secure Michigan's spot as the home to the future of electric vehicles."**

**- Karen from Detroit**

## Reduced costs for working families

Climate action will also lower costs for working families and small businesses. To achieve our GHG reduction goals, Michigan must make transformative investments in weatherizing and reducing energy waste in our homes and places of business. Combined with the increased use of renewable energy, this will lower the monthly utility bills for Michigan families and businesses. At the same time, the transition to electric vehicles will reduce costs related to fueling and maintaining our cars, while improved public transit will help Michiganders cut the share of our incomes spent on transportation and provide the [8% of Michigan households](#) without personal vehicles greater access to jobs and other opportunities.

Examples of the powerful math behind these benefits include the following:

- For every \$1 invested in reducing energy waste in our homes – through more efficient windows, lighting, and other energy-saving technologies – [homeowners save more than \\$3.20](#) in reduced future energy bills. Energy efficiency also reduces energy burden by as much as 25 percent, translating into more than [\\$400 in annual savings for households](#).
- The [levelized cost of electricity](#) for new onshore wind and solar resources that are coming online in 2023 was \$25.55/MWh and \$25.89/MWh respectively, compared with \$34.78/MWh for new combined-cycle natural gas units. Adding new wind and solar resources is comparable – and in many cases cheaper – to the cost of running existing power plants.
- Michigan sends [billions of dollars out-of-state](#) annually to purchase fossil fuels. If we produce more of our energy right here in Michigan from clean, renewable resources, we will be more energy independent and lower costs for working families.
- Owners of electric vehicles are expected to [save between \\$6,000 to \\$10,000](#) over the life of the vehicle, compared to a gas-powered vehicle, because charging is half as expensive as the equivalent amount of gas and electric vehicles require half as many repairs and cost half as much to maintain.



**“We recently bought an electric vehicle, installed solar panels on our roof, and switched to a geothermal HVAC. We're saving money on utility bills and gasoline without compromising any of our needs. When I tell people about this, they wonder how I could afford it. There are a lot of generous financing options and federal tax credits for these investments. Depending on the project, the payments might be around the same as the energy savings and the project will pay for itself right away! You can make modest investments, lower your bills, and be a part of the climate solution right now.”**

**– John, Farmington Hills resident**

## High cost of inaction

While the opportunities to create good jobs, cut costs, and grow our economy should be more than enough to inspire ambitious action to decarbonize our economy, it is also important to remember that climate *inaction* will come at a high price for Michiganders. Climate change increases the likelihood of natural disasters, damaging infrastructure that is costly to repair and disrupts business. More erratic and unpredictable temperatures lead to uncertainty and losses for our farmers and other sectors that rely on seasonal consistency. And extreme weather worsens health outcomes leading to lost productivity and wages.



Michigan currently spends millions of dollars annually responding to climate-related emergencies and other impacts. Early intervention is a much sounder strategy with a much better return on investment. According to a recent study, the state will avoid **\$4 to \$11 worth of future damages** for every **\$1 it commits to climate adaptation**.

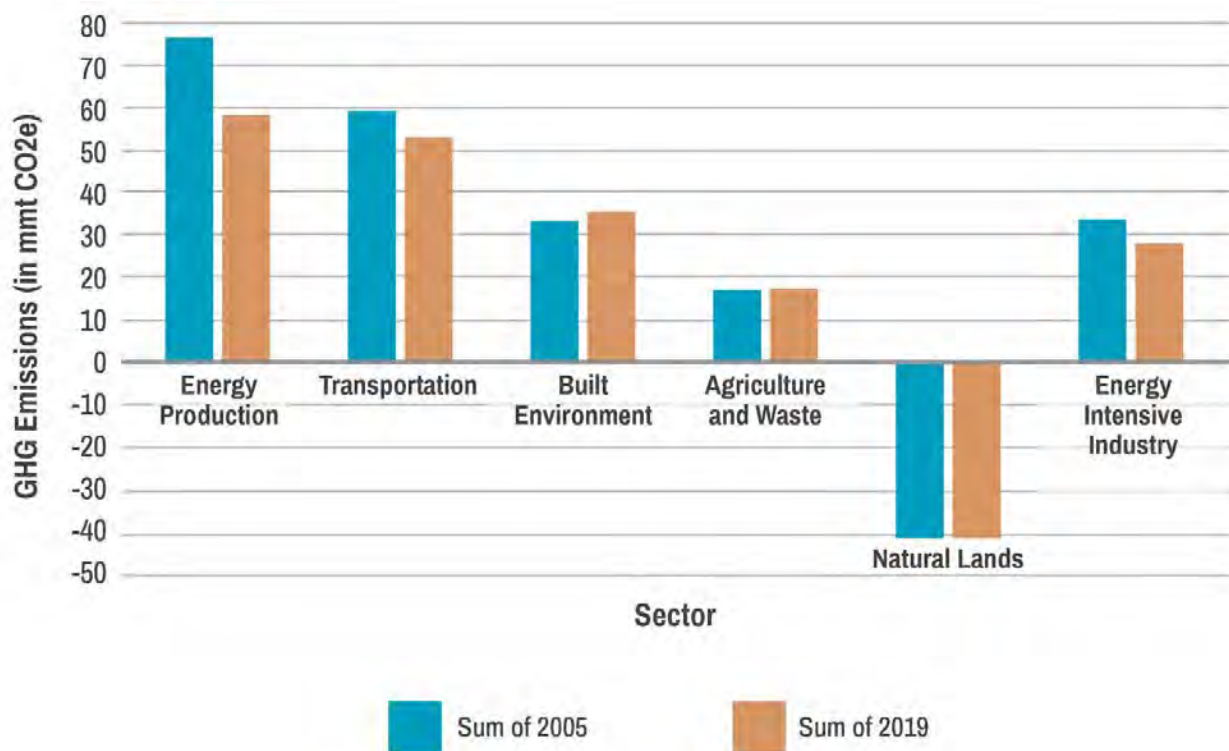
Climate action will spur innovation, increase the state's economic competitiveness, create good-paying jobs for Michigan workers, and cut costs for working families. This Plan sets the state on track to a more prosperous and sustainable Michigan.

## MICHIGAN'S GREENHOUSE GAS EMISSIONS

Governor Whitmer's emissions reduction goals use a 2005 baseline for Michigan's GHG emissions, which can be categorized into five key sectors: energy production, transportation, the built environment, natural and working lands, and energy-intensive industries. The following uses [Rhodium Group's 2021 emissions outlook data](#) to summarize the share of Michigan's GHG emissions that come from each sector and provide a basic sense of the task ahead and the areas of our economy with the furthest to go in our quest for carbon neutrality.

The electric power sector and the transportation sector are the state's two leading sources of GHG emissions with the transportation sector set to eclipse the electric power sector imminently. Emissions from heating Michigan's buildings and running fossil-fuel-burning appliances account for the third largest contribution. Energy-intensive industries contribute a similar level of emissions to buildings—from onsite fuel usage and emissions inherent in certain industrial processes like cement manufacturing. Natural and working lands – which include emissions from agriculture and land-use changes (i.e., developing green spaces or impacting wetlands) – contribute the smallest percentage of overall emissions. However, because natural and working lands also present an opportunity to capture GHG emissions—an important piece of the carbon neutrality puzzle—they should not be undervalued or overlooked.

**Greenhouse Gas Emissions by Source**





## **ENERGY PRODUCTION**

In 2005, the power sector in Michigan emitted 76.55 million metric tons (mmt) of carbon dioxide equivalent emissions (CO<sub>2</sub>e). Those emissions came primarily from coal-fired power plants, followed by natural gas power plants. Michigan also benefits from a diverse power sector that includes nuclear power plants and the pumped hydro facility at Ludington. Through the closure of coal plants and the expansion of renewable energy resources, power sector emissions in Michigan fell to 58.2 mmt CO<sub>2</sub>e in 2019 – a 24 percent decrease over that decade and a half period.

## **TRANSPORTATION**

In 2005, the transportation sector in Michigan emitted 59.26 mmt CO<sub>2</sub>e. Most of those emissions came from light-duty passenger vehicles and heavy-duty freight trucks (our state of 10 million people has nearly 7 million vehicles!). As electric vehicles became more available and modern internal combustion engine (ICE) vehicles became more fuel efficient, transportation emissions dropped slightly to 53.04 mmt CO<sub>2</sub>e in 2019 – a 10 percent reduction since 2005.

## **BUILT ENVIRONMENT**

In 2005, homes and businesses emitted 33.39 mmt CO<sub>2</sub>e, mostly from the use of sources like natural gas, fuel oil, or propane for heating and appliances. Driven by increased emissions from commercial buildings, this sector saw a slight uptick to sector-wide emissions of 35.61 mmt CO<sub>2</sub>e in 2019.

## **ENERGY-INTENSIVE INDUSTRY**

In 2005, Michigan's oil, gas, and industrial sectors emitted 33.78 mmt CO<sub>2</sub>e. Michigan has a rich history of manufacturing, and most of these emissions came from the process of producing new goods, like iron, steel, cement, and chemicals. Industry is always innovating and improving efficiency, leading to reduced emissions of 28.05 mmt CO<sub>2</sub>e in 2019 – a 17 percent change in the right direction.

## **NATURAL AND WORKING LANDS**

Michigan has a unique diversity of land uses and ecosystems. Agricultural soil management is a major source of emissions from this sector, primarily from the large-scale farm operations in the southern portion of the state, while the forests in the north are the state's major carbon sink. This sector's net GHG emissions have remained almost unchanged over the past decade and a half. Agriculture and waste sources emitted 17.12 mmt CO<sub>2</sub>e in 2005 and 17.37 mmt CO<sub>2</sub>e in 2019. Natural lands sequestered 41.35 mmt CO<sub>2</sub>e in 2005 and 41.41 mmt CO<sub>2</sub>e in 2019.

While our emissions are projected to stay on a downward trend, we need to accelerate reductions across all sectors to meet our decarbonization goals on our established timelines. Reducing our emissions at the scale necessary will take concerted action at the international, federal, state, local, and individual levels. To track progress of the MI Healthy Climate Plan and help identify the areas for greatest GHG reduction potential, Michigan will develop a GHG inventory working with public and private partners and stakeholders.

## A CARBON NEUTRAL MICHIGAN

While we are immediately focused on the short-term—and the objectives in the [Roadmap to 2030](#) section below—our long-term goal to achieve economy-wide carbon neutrality by 2050 is no less urgent. Economy-wide carbon neutrality means that every sector of Michigan’s economy – energy production, transportation, built environment, natural and workings lands, and energy-intensive industry – will work together to meet our decarbonization goals. Reaching our mid-century milestone will require particularly substantial effort and innovation in the sectors of our economy that are hardest to decarbonize, including industry, buildings and housing, and agriculture. Since these sectors will take strategies and approaches that are not yet fully developed, we must start now. Also, we cannot take steps between now and 2030 that will jeopardize our ability to meet our 2050 goal.

But what does a carbon neutral Michigan look like? If we take a creative, strategic, and aggressive approach to reducing our GHG emissions, Michigan will be a state where residents enjoy better health outcomes and an improved quality of life; working families have more opportunities, high-paying jobs, and a lower cost of living; equity is centered in every decision; our global leadership in clean innovation and related economic development drives sustained prosperity; and everyone has greater access and a deeper connection to our state’s natural beauty.





# In Michigan in 2050...

As we implement the strategies in this Plan and transition Michigan to a thriving carbon neutral economy—while mitigating and adapting to the negative impacts of climate change—Michigan can take transformative steps toward a future in which:

**Every individual has clean air to breath and clean water to drink.**

**Every business and household has access to affordable energy sourced from reliable, clean energy.**

**Every worker has a good-paying, sustainable job to support their family.**

**Every resident has access to clean, affordable transportation.**

**Every family lives in a healthy, sustainable, efficient home.**

**Every individual has easy access to healthy, affordable, local food.**

**Every resident has safe, natural spaces to enjoy.**

**Every community has the resources to be resilient to the impacts of climate change.**

**Michigan has addressed racial disparities in health outcomes.**

**Michigan is globally known for its leadership in clean innovation and industry.**

**Michigan's land and resources are abundant and healthy.**

**Michigan has mitigated the worst impacts of climate change and worked to adapt and become resilient to existing impacts of climate change.**

As we look to this bright future, we know the best solutions to achieve these goals will emerge and evolve through innovations in technology, strategy, and policy, as well as individual and community level problem-solving. This work must start now and continue through 2050 and beyond.

## A ROADMAP TO 2030



The State of Michigan has committed to carbon neutrality by 2050 with 52 percent GHG emissions reductions by 2030 as an interim target. Achieving our 2030 goal will require Michigan to reduce annual GHG emissions by approximately 92.95 million metric tons of CO<sub>2</sub> equivalent based on today's emissions levels.

Sustained, aggressive action across Michigan's economy is necessary to reach these targets. A variety of factors will determine the extent to which various sectors and subsectors reduce emissions during this time, including technological breakthroughs and constraints, economic opportunities and costs, and public support/consumer demand for change.

The MI Healthy Climate Plan intends to spur the changes that are imperative—that must happen, and happen now, to meet our goals. It also seeks to shape *how* Michigan achieves carbon neutrality by recommending strategies that will maximize the benefits for Michigan families from decarbonization. To that end, the Plan focuses most heavily on the three sectors with the greatest opportunity for rapid and substantial gains in GHG reductions—energy production, transportation, and the built environment. It also prioritizes environmental justice across all actions and spotlights pathways to carbon neutrality that will lead Michigan to better health outcomes, good jobs, and economic prosperity for all Michiganders.

This 'Roadmap' provides recommendations but should not limit additional actions. State government, local governments, tribal governments, and private institutions should strive to move beyond these recommendations and seek innovation and new approaches to reduce GHG emissions. Across all sectors, Michigan should use every tool and chase every dollar available, including Infrastructure Investment and Jobs Act funds, to help meet our climate goals.



**NOTE:** This section borrows liberally from the concepts and language that the five topical workgroups submitted to the Council on Climate Solutions along with their recommendations. The workgroups included: Energy Production, Transmission, Distribution, and Storage; Transportation and Mobility; Buildings and Housing; Energy Intensive Industries; and Natural and Working Lands and Forest Products. In addition to the above-listed workgroups, an internal group led by EGLE staff provided recommendations on decarbonization related to materials management. This section intentionally includes environmental justice recommendations in every sector, not just the environmental justice section.

## Key Recommendations

In the pages that follow, this Roadmap offers several recommendations in each of the areas below with a brief background discussion of each. A brief summary of key recommendations is provided here.

**Commit to Environmental Justice and Pursue a Just Transition:** Ensure that at least 40 percent of state funding for climate-related and water infrastructure initiatives benefit Michigan's disadvantaged communities (in line with the federal government's Justice40 guidelines for federal funding); that Justice40 is developed in partnership with leaders in disadvantaged communities; and that Michigan emphasizes a just transition for all workers through proactive engagement, job training, and workforce development.

**Clean the Electric Grid:** Generate 60 percent of the state's electricity from renewable resources and phase out remaining coal-fired power plants by 2030. Limit energy burden from powering and heating homes to not more than 6 percent of annual income for low-income households.

**Electrify Vehicles and Increase Public Transit:** Build the infrastructure necessary to support 2 million electric vehicles on Michigan roads by 2030. Increase access to clean transportation options – including public transit – by 15 percent each year.

**Repair and Decarbonize Homes and Businesses:** Reduce emissions related to heating Michigan homes and businesses by 17 percent by 2030. Increase investments in repairing and improving buildings to reduce costs for working families and small businesses.

**Drive Clean Innovation in Industry:** Encourage clean innovation hubs where private enterprises strategically co-locate and collaborate to develop and deploy new, cleaner manufacturing technologies and conduct research and development to reduce emissions from hard to decarbonize industries. Triple Michigan's recycling rate to 45 percent and cut food waste in half by 2030.

**Protect Michigan's Land and Water:** Protect 30 percent of Michigan's land and water by 2030 to naturally capture GHG emissions, maintain and improve access to recreational opportunities for all Michiganders, and protect biodiversity. Leverage innovative strategies to support climate-smart agriculture.

## COMMIT TO ENVIRONMENTAL JUSTICE AND PURSUE A JUST TRANSITION

We are committed to addressing past, present, and future environmental injustices and providing equitable access to the jobs and other benefits of Michigan's carbon neutral future. This section of the Plan focuses on policies and programs that will ensure the equitable treatment and meaningful participation of all Michiganders in that future.

### Key Strategies

- **Justice40** – Ensure that at least 40 percent of state funding for climate-related and water infrastructure initiatives benefit Michigan's disadvantaged communities, in line with the federal government's Justice40 guidelines for federal funding. Develop Justice40 in close partnership with leaders in disadvantaged communities.
- **Environmental justice analysis** – Engage all state agencies in determining how environmental justice screening tools can assist them in designing better information gathering, outreach, engagement, and decision-making processes to reduce existing and future impacts to residents (this includes permitting decisions). Expand on the efforts of the Michigan Public Service Commission to conduct an environmental justice and health impact analysis as part of Integrated Resource Planning (IRP) so the potential community impacts of utility investment decisions are more fully considered.
- **Workforce development and job training** – Strengthen and create workforce development, job training, pre-apprenticeship/apprenticeship, joint labor management training, and other such programs for in-demand clean energy jobs – from pre-weatherization services to grid maintenance, electric vehicles, and renewables. Ensure these programs are federally certified by the Department of Labor where applicable. Incentivize workforce development and training for workers experiencing energy-related employment transitions and those in underrepresented or disproportionately impacted communities.
- **Just transition** – Expand transparency around the Energy Transition Impact Project's work and provide financial support and best practices to communities addressing economic transitions from closures of fossil fuel facilities and other large industrial operations. Work with employers and other partners to develop sector-specific retraining solutions.
- **Development, retention, and attraction of clean energy businesses** – Expand efforts to support business development, retention, and attraction around clean energy businesses. Conduct trainings to support minority-owned, veteran-owned, women-owned, tribal-owned clean energy businesses and help them compete in utility and state procurement programs. Identify tools and best practices to expand opportunities for these firms in Michigan.

Beyond committing to the actions above, this Roadmap includes recommendations infused with environmental justice considerations in each of the major GHG-emitting sectors. For example, this Plan also includes commitments to reduce energy burden for disadvantaged communities, strengthen ratepayer input at the Michigan Public Service Commission (MPSC), and spur more equitable investments in energy saving home repairs, public transportation, and clean energy solutions for schools.

## Background

The State of Michigan should be a place where everyone has the opportunity to thrive, no matter their zip code or the contents of their wallet. This includes the opportunity to enjoy the dignity of good work and live in a healthy community with access to affordable housing, water, and utilities. Unfortunately, this has not always been the case, particularly for Black, brown, indigenous, and low-income people.

[The United for ALICE project](#) documents the struggle experienced by the Asset Limited, Income Constrained, Employed segment of our population. It shows that even with unemployment at record low levels, much of our population struggles to make ends meet. In Michigan as a whole, 38 percent of the population falls into this category with 13 percent below the poverty line and 25 percent above it but still not making ends meet. More than half of Michiganders across much of the Upper Peninsula and the central portion of the Northern Lower Peninsula fall into this category. In Detroit, the figure is approximately 70 percent.

These Michigan families face daily “choices” between paying rent, staying current on utility bills, and buying food for their children. With limited resources, they are also particularly vulnerable to the extreme weather, economic transitions, and other impacts of climate change. If Michigan does not proactively intervene, climate change will only deepen these existing harms and inequities. We must seize our transition to carbon neutrality as an opportunity to chart a new path.

## Guarding against future challenges

Many of the strategies laid out in this plan will help right environmental justice wrongs from the past. Renewable energy and electric vehicles will help clean the air, and green infrastructure will help keep our cities cooler and utility bills lower.

However, if we are not deliberate in moving toward an environmentally just future, we run the risk of creating new inequities as we transform the way we create and consume energy. For example, electric vehicles are not yet affordable or accessible for all Michiganders, so the Plan includes a broad transportation decarbonization strategy to make walking, biking, and public transit more accessible to Michigan families and electric vehicles cheaper and easier to charge.

In the electric sector, there is no automatic guarantee that retiring coal facilities and increasing use of other electric generation assets – current or future – will benefit Michigan communities. That is why the Plan calls for holistic energy planning and increased consideration of environmental justice in decision making. Additionally, while more renewable energy will help all Michiganders, access to the benefits of renewable energy may not be equitable. Thus, the Plan calls for funding programs focused on Michigan’s disadvantaged communities. Finally, we must take particular care to ensure that the energy transition does not result in a disproportionate energy burden for Michigan’s disadvantaged communities. In other words, we must do everything we can to avoid a future in which utility bills cost families in those communities an even greater share of their disposable income.

Our frontline communities will also be hit first and hardest by the impacts of climate change. An environmentally just future includes making sure that no one experiences disproportionate harm from the extreme heat and precipitation that Michigan will experience over the next century no matter how quickly we decarbonize. This Plan does not contain a holistic adaptation and resilience strategy, though resilience will be core to our Plan implementation work.

## Justice in funding decisions

In January 2021, the White House created the [Justice40 Initiative](#) by executive order. It aims to deliver to disadvantaged communities 40 percent of the overall benefits of relevant federal investments. As a part of this Plan, Michigan has committed to aligning our relevant federal and state investments with this initiative.

The State is currently waiting for guidance from the federal government on how to effectively implement Justice40. The State will also actively seek input from environmental justice communities, tribal governments, and other stakeholders as we define the scope, benefits, and community qualifications for this initiative and determine how to best implement Justice40 and track progress.

## Inclusive and transparent engagement and decision-making

In addition to funding decisions, we must ensure all state agencies are considering environmental justice across their operations and decision making.

As mentioned above, the Plan calls for all state agencies to evaluate current information gathering, outreach and engagement, and decision-making processes and determine how environmental justice screening tools can assist them in avoiding and correcting disproportionate impacts on disadvantaged communities.

It also calls for the expansion and improvement of efforts initiated by EGLE and the MPSC to conduct an environmental justice and health impact analysis as part of utility Integrated Resource Planning, so that the potential community impacts of utility investment decisions are more fully and faithfully considered. The Plan also includes multiple opportunities to support meaningful engagement of Michigan's environmental justice communities, including calling for additional funding for the Utility Consumer Representation Fund, which is managed by the Utility Consumer Participation Board, to support ratepayer advocates in their interventions at the MPSC.

As the Plan is implemented, the OCE will establish consistent and transparent practices for engaging

## EXPANDING ON THE WORK OF THE ENVIRONMENTAL JUSTICE PUBLIC ADVOCATE

In 2019, through [Executive Order 2019-06](#), Governor Whitmer created the [Office of the Environmental Justice Public Advocate](#) (OEJPA).

To gather input from impacted communities, the OEJPA has hosted 8 regional roundtables across the state to discuss environmental justice challenges and identify opportunities to pursue more just outcomes in environmental decision-making. It has led the State of Michigan in developing the Michigan [Environmental Justice Screening Tool](#), an interactive mapping tool that identifies Michigan communities that may be disproportionately impacted by environmental hazards. The map will allow users to explore the environmental, health, and socioeconomic conditions within a specific community, region, or across the entire state.

The OEJPA is also working directly with partners in individual communities, including a new pilot to build a [Community Resiliency Plan](#) in the 48217-zip code in Southwest Detroit. And the office coordinates initiatives with Michigan's tribal governments, like the [Michigan Wild Rice Initiative](#), which brings together specialists and managers from all 12 federally recognized tribes, multiple state departments and federal agencies, and others to share information, coordinate approaches, and elevate awareness about wild rice conservation and restoration.

environmental justice communities in close collaboration with existing bodies like the MAC-EJ. In addition, the OCE will ensure robust engagement with tribal governments continues through the existing tribal consultation process.

### **Invest in workforce and a just transition**

As we transition to a decarbonized economy with more efficient buildings, increased renewable energy sources, and expanded electrified transportation solutions, Michigan must invest in our workforce. We need to be prepared to capture new, good-paying jobs for Michigan workers and support those who may need to transition as the economy changes. Michigan is committed to ensuring no Michigan workers get left behind.

In 2020, Governor Whitmer launched the [Energy Transition Impact Project \(ETIP\)](#) under the leadership of the Department of Treasury. ETIP is designed to identify communities that will be impacted by the changes to the mix of energy production facilities in Michigan. The program works directly with those communities and workers to minimize impacts from a facility closure, including the loss of employment, property tax revenues, and related community services. Comprehensive transition strategies are developed to reposition communities for future economic development, high-paying jobs, new infrastructure investments, housing improvements, and other needs identified by local leaders and residents.

In addition, to support worker transitions and keep Michigan competitive for the clean energy jobs of the future, State of Michigan programs expanded their focus on high-quality workforce development, job training, pre-apprenticeship and apprenticeship, and joint labor management trainings for in-demand clean energy jobs. And, to make sure there is a demand for graduates of these programs, the Plan includes business development, retention, attraction, and other supports for minority-owned businesses in the clean energy industry. It is critical that workers who may be displaced by the energy transition—and residents who have been disproportionately impacted by climate change—are able to take advantage of new clean energy job opportunities.





## CLEAN THE ELECTRIC GRID

In 2019, Michigan's power sector contributed approximately 30 percent of Michigan's total GHG emissions. In 2020, coal and natural gas, the two primary sources of GHG emissions in the power sector, provided 59 percent of all electricity generation in the state. To meet our climate goals, Michigan will need to increase the adoption of wind and solar generation, increase energy waste reduction, invest in grid infrastructure and planning, and ensure that all of these actions are done in a manner aligned with environmental justice.

### Key Strategies

- **Clean energy resources** – Generate 60 percent of the state's electricity from renewable resources by adopting a renewable energy standard of 50 percent by 2030, supporting voluntary utility green pricing programs, and creating more favorable conditions for customer-sited behind-the-meter distributed energy resources like rooftop solar. Work with Michigan utilities to effectively phase out coal-fired power plants.
- **Holistic and integrated energy system planning** – Improve energy system planning by fully integrating traditional resources, transmission, distribution, new and emerging resources, and considerations related to the interdependency of electric and natural gas systems. Elevate community health impacts and equitable access to infrastructure in energy planning and investment decisions. Continue to develop and refine innovative rate designs to incent behaviors that advance clean energy goals.
- **Affordability and energy burden** – Limit energy burden from powering and heating homes to not more than 6 percent of annual income for low-income households. Increase affordability of utility services through expanded "Percent of Income Pilot Programs" and through minimum allocation levels for utility investment in low-income energy efficiency programs. Direct additional funding to the Michigan Utility Consumer Representation Fund (UCPF) to provide resources to intervenors in MPSC proceedings who represent the interests of low-income communities.
- **Siting** – Assist clean energy developers and communities in adopting best practices for siting renewable energy systems. Implement a plan to site solar on state-owned lands and properties as quickly as possible.
- **Energy storage** – Adopt a statewide storage target to deploy 4,000 Megawatt (MW) of grid scale storage by 2040 with a short-term target of 1,000 MW by 2025 and a medium-term target of 2,500 MW by 2030. Increase consideration of energy storage resources in utility Integrated Resource Plans through accurate modeling.

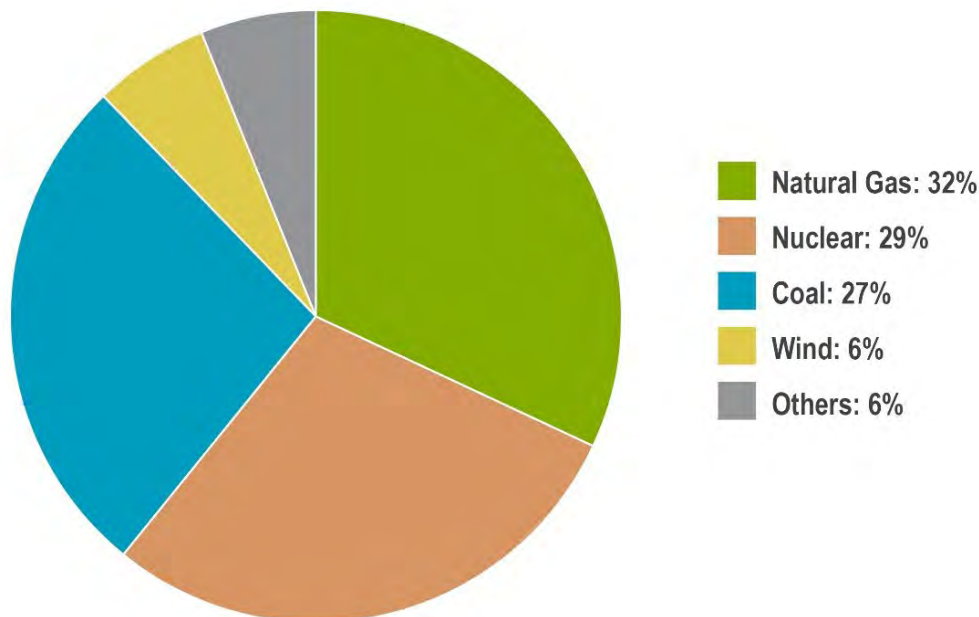
### Background

To reach our climate-related goals, attract clean energy jobs, and drive down costs for Michiganders, rapid and comprehensive action is needed in the electricity sector. In fact, bolder action is particularly wise here—relative to other sectors—because of the cost-effective and scalable nature of decarbonizing the electricity sector.

This Plan’s recommendations prioritize five key strategies for transforming the electricity sector: accelerating the adoption of renewable energy like wind and solar; retiring coal and other fossil fuels; investing in energy waste reduction measures that drive down costs for Michiganders; improving infrastructure and planning to ensure resource adequacy; and making sure all efforts are done with environmental justice in mind.

It is important to note that energy waste reduction is a key strategy in the electricity sector, but it is addressed more robustly in the “Repair and Decarbonize Homes and Businesses” section of the Plan.

### Michigan Electric Generation



### Drive Adoption of Renewables

Michigan’s progress over the last decade has shown that an economy powered by clean, renewable electricity is not only possible but increasingly preferred. Currently, renewable energy generates [about 11% of Michigan's total in-state electricity](#). As deployment has increased and the wind, solar, energy storage, and related industries have scaled up, the cost of renewable energy has continued to fall. According to the [MPSC](#), it cost energy providers an average of \$64.48 per megawatt hour to purchase renewable energy in the period from 2009 to 2020. However, in some cases, recent contracts have dropped in cost by more than 35 percent, thus making them significantly less expensive and more stable for major energy providers than non-renewable resources.

Nearly all of Michigan's electric utilities have made individual commitments to reduce carbon emissions, with some utilities pursuing levels of renewable energy deployment beyond what is required under the state's existing mandates and goals. They are also retiring their fleets of aging coal-fired plants. According to utility retirement schedules, just one coal-fired power plant is scheduled to continue operating after 2028.

Despite this progress, Michigan will need a massive scaling up of renewable energy to achieve 60 percent renewable energy penetration this decade and reach carbon neutrality by 2050. To reach that 2030 target, Michigan must adopt a renewable energy standard of 50 percent by 2030 through the passage of legislation or via formal commitments from Michigan's utilities in proceedings before the Michigan Public Service Commission. As a demonstration of the feasibility of that standard, Michigan's investor-owned utilities already have plans in place to dramatically scale up their renewables. Taking solar for example, [DTE](#) intends to have at least 10 million panels in its generation mix by 2040, and [Consumers Energy](#) is planning for 8,000 MW built by the same year.

While a 50 percent renewable energy standard serves as a foundation, higher levels of renewable energy penetration will be necessary to achieve our goals and customer-enabled renewable energy will play a central role in additional gains. In Michigan and across the country, large companies and customers are helping to drive the increased adoption of renewable energy through tools like voluntary green pricing programs, customer-sited distributed energy, community solar, demand response, battery storage, and more. By encouraging the most-cost effective investments in clean energy resources for all energy customers, including supporting customer-sited resources, we can increase options for customers to participate in the fight against climate change and make our electric grid more resilient.

Of course, adoption of renewable energy on the scale necessary to achieve our goals will require Michigan to responsibly locate wind, solar, and storage in communities across the state. Local siting challenges have been well documented as a limiting factor in Michigan's path to reaching carbon neutrality. Through Michigan's [Catalyst Communities](#) program and tools like [EGLE's Renewable Energy Ordinance Database](#), the state will expand support for local units of government to adopt best practices for siting renewable energy systems within their communities.





## Transition away from fossil fuels

Retiring coal facilities on an accelerated timeline is fundamental to reaching Michigan's near-and long-term climate objectives. The Plan recommends that Michigan complete its transition away from coal-fired generation for powering our homes and businesses no later than 2030. It also calls for energy planning that will include options for reducing reliance on natural gas and other pathways for decarbonizing the electricity sector that go beyond coal plant retirement. As this transition takes place, Michigan must invest in support systems for workers displaced from fossil-fuel-powered generation facilities and ensure resource adequacy through investments in new generation assets and improved transmission, distribution, and storage.

## Ensure resource adequacy through investments in infrastructure and planning

Building on the current IRP process at the MPSC—[established with the passage of the 2016 energy laws](#)—Michigan is well-positioned to undertake a comprehensive energy planning process to ensure reliability, affordability, and the cost-effective integration of new technologies as the sector decarbonizes. Comprehensive energy planning includes rate design, traditional resource planning, long-range transmission planning, distribution planning, storage planning, consideration of new and emerging resources, planning around areas of interdependency between the electric and natural gas systems, consideration of community and health impacts, and identification of viable decarbonization pathways aligned with carbon neutrality by 2050.

To help ensure reliability and affordability for ratepayers while we decarbonize this sector, Michigan must continue to invest in transmission and distribution infrastructure and maintain existing clean energy and energy storage assets. In addition, Michigan must invest more robustly in grid scale energy storage through a deployment target of an additional 2,500 MW by 2030 and 4000 MW by 2040.

## Ensure affordability and justice

Energy burden is the percentage of household income that a given household spends on home heating and electricity costs. Energy burden is often much higher in low-income households, where residents may be unable to afford energy efficiency upgrades to their existing homes or the purchase of more expensive homes that are already energy efficient. [For example](#), in 2018, households with an income between 0-30 percent of the state median had an average energy burden of 24 percent, compared to an average energy burden of 2 percent for households with an income at or above the state median. Michigan must develop and expand utility programs to ensure no low-income household is paying more than [6 percent of their annual income on energy](#). As these programs are developed, Michigan should increase funding to the UCRF, which is overseen by the Utility Consumer Participation Board, with the express intent of allowing for more participation from disadvantaged communities in the design of these programs.

## ELECTRIFY VEHICLES AND INCREASE PUBLIC TRANSIT

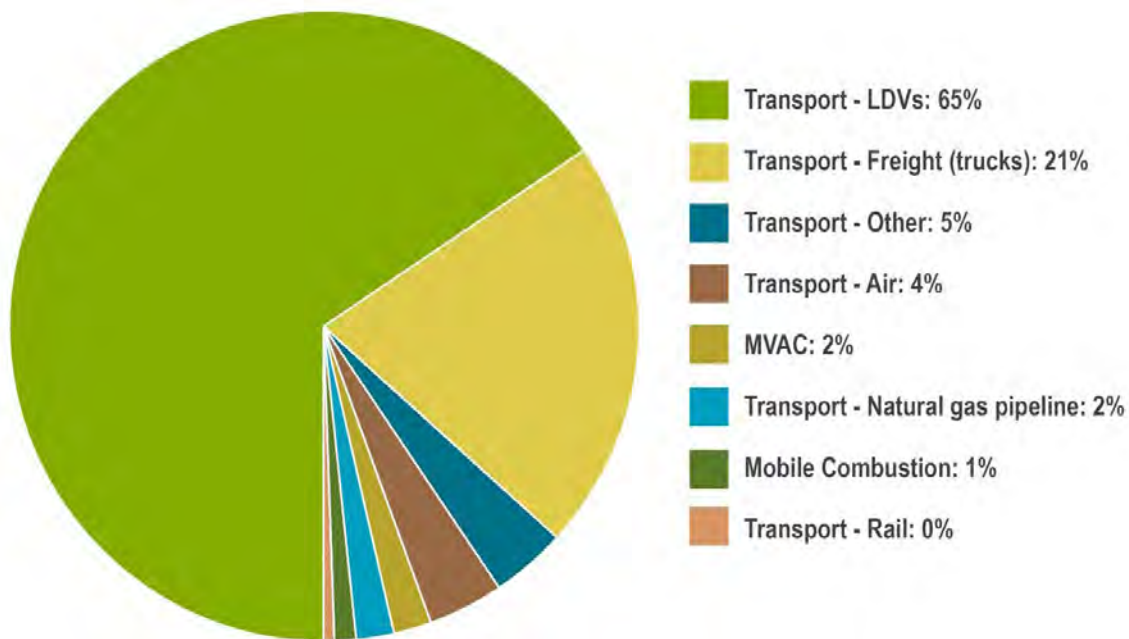
As of 2019, Michigan's transportation sector accounted for almost 28 percent of the state's total GHG emissions, the second highest emitting sector after the power sector. Transportation emissions are primarily due to the combustion of petroleum products such as gasoline and diesel in light-duty vehicles and freight trucks.

It will take a broad, all-options approach to transportation to put Michigan on track to achieve its decarbonization goals, increase equity, and offer new economic opportunities to Michiganders. To decarbonize how Michiganders move, Michigan will need to drive a rapid transition to cleaner fuels and electrification, make unprecedented investments in electric vehicle charging infrastructure, increase access to diverse transportation options, and focus on integrated people- and planet-focused transportation planning.

### Key Strategies

- **Purchase incentives** – Create and fund an incentive program for the purchase of electric vehicles and at-home charging stations. Explore incentives for products like electric off-road vehicles, electric recreational vessels, and e-bikes.
- **Electric vehicle charging** – Build the infrastructure necessary to support two million electric vehicles on Michigan roads by 2030. Leverage the success of the Charge Up Michigan program to equip Michigan with a comprehensive, accessible network of chargers using various financing tools, including public funding opportunities and public-private partnerships.
- **Electrified fleets** – Transition the State of Michigan's fleet to 100 percent zero-emission vehicles. Fund and support local governments and small businesses with fleet transitions and work with schools to quickly electrify school bus fleets, with a prioritization on communities with high levels of air pollution.
- **Clean Fuels Standard** – Adopt a Clean Fuels Standard (CFS) to reduce the carbon intensity of every fuel in use.
- **Transit and diverse transportation options** – Increase access to clean transportation options – from public transit to electric vehicles – by 15 percent each year. Work with communities that are mobility insecure to set community-specific targets to expand access to clean transportation options. Increase investment in more efficient, cleaner public transit systems—as well as bike paths, walking trails, and other such infrastructure—to offer the broadest possible range of options to residents.
- **Transportation planning** – Implement a Safe Systems Approach in transportation planning to work towards the elimination of fatal and serious injuries for all road users. Develop a transportation strategic plan focused on electrification to guide state agencies in moving Michigan toward our cleaner mobility future. Consider creation of a statewide electrification plan for transit.

### Transportation Greenhouse Gas Emissions by Sub-Sector Source



#### Background

For over a century, Michigan has enjoyed global automotive leadership. To remain at the forefront, the State needs to lead on the transition to electric vehicles, invest in infrastructure, support the retraining of our transportation workforce to ensure all workers transition into new high-paying jobs, and provide an attractive business environment for our auto industry.

While vehicle electrification is a key technology needed to meet 2050 decarbonization goals for the transportation sector, it cannot be the only decarbonization solution for Michigan. Michigan needs to employ multiple strategies and effective planning to achieve our state's transportation decarbonization goals and mobility needs as the transition to electrification unfolds over time.

#### Transition to cleaner fuels and electric vehicles

Electric vehicles represent a small fraction of Michigan's current auto sales today. Just [0.62 percent](#) of all vehicles sold here in 2020 were electric. Two of the key current barriers to widespread uptake are the higher purchase cost typically associated with these vehicles and the real or perceived lack of electric vehicle charging infrastructure.

To address these challenges, the State of Michigan will develop purchase incentives targeted to spur sales of electric vehicles throughout Michigan, particularly in the near-term to stimulate market growth and help more Michiganders access clean transportation options. To lead by example on this path, the State of Michigan will transition its fleet to 100 percent zero-emission vehicles by 2035 for light-duty vehicles and 2045 for medium- and heavy-duty vehicles. Leveraging this leadership, the State will also expand funding options for fleet conversions for local governments, small businesses, and school bus fleets, with a prioritization on communities with high levels of air pollution.

To build out the necessary charging network, Michigan will expand funding opportunities for direct current fast charging stations to make sure that Michigan residents can drive an electric vehicle throughout the state without anxiety over where to get their next charge. Through [Charge Up Michigan](#), the State has already invested more than \$45 million in charging infrastructure and will spend millions more in the coming years thanks to the recent and forthcoming influx of additional federal resources. By expanding funding through the Charge Up Michigan program and partnering with utilities and the private sector, Michigan will deploy enough charging infrastructure to support two million electric vehicles on Michigan roads by 2030. In pursuing that 2030 target, Michigan should aim for electric models to account for at least 50 percent of light-duty vehicle sales, 30 percent of medium- and heavy-duty vehicles sales, and 100 percent of public transit vehicles and school buses sold that year.



Michigan should also pass legislation to adopt a CFS, a technology-neutral, performance-based policy to reduce the carbon intensity of transportation fuels. These standards ratchet down carbon emissions in the transportation sector over time, increasing the use of lower-carbon fuels and reducing the use of higher carbon fuels. By setting a standard that grows more stringent over time, the program will dramatically increase private investment in lower carbon fuels. While providing added encouragement and support for the emerging electrified transportation sector, this policy can also incentivize the use of lower-carbon liquid fuels in non-electric vehicles during the transition to a fully electric future. In addition, a CFS can be designed to create revenue for reinvestment in electric vehicle purchase incentives or charging infrastructure. This policy is a critical bridge between the status quo's carbon-intensive fuels and electrification.

### **Increase access to diverse transportation options**

Vehicle electrification cannot be the only transportation decarbonization solution for Michigan. Vehicle fleets have inherently slow turn-over rates. The vast majority of vehicles on Michigan's roads will still be burning gasoline in 2030, even if we adopt the market incentives recommended in this Plan and automakers aggressively pursue their electric vehicle sales goals. In light of this reality, Michigan needs to employ multiple strategies to achieve our transportation decarbonization goals as the transition to electrification unfolds over time. Expanding access to safe and convenient public transit, mobility solutions like car sharing, and high-quality bike and walking infrastructure will play a vital role in decarbonization.

Better and more widely available transit also represents an opportunity to advance equity. It increases access to opportunities to learn, earn a living wage, and remain healthy for the many Michigan families that currently lack reliable transportation. [Almost eight percent of Michigan households](#) have no vehicle at all, and that number more than doubles to 19 percent for renters. Nearly 3 out of every 5 jobs cannot be reached by public transit, meaning that these opportunities are not equitably accessible to all Michigan families. This is particularly true for non-white households, which make up 79 percent of transit riders. Public transportation is also the best transportation option—and in some cases the only viable one—for many seniors and Michiganders with disabilities. This Plan sets goals to diversify transportation options and increase investments in public transit and related mobility solutions.

### **Implement people and planet focused transportation planning**

Strategic transportation planning will help knit traditional and advanced transportation options into an integrated system that serves all Michiganders equitably. As Michigan develops a statewide electrification plan and related tools to do just that, coordination will be critical given the many key players involved, including local, state, and federal agencies and a great variety of private partners.

The Plan also recommends the implementation of a [Safe Systems approach](#) to transportation planning that focuses on safe mobility for all road users. Implementing the Safe System approach means anticipating and proactively planning for road user mistakes through the design and management of road infrastructure and the development of rules and regulations for drivers that lower the risk of death or serious injury.



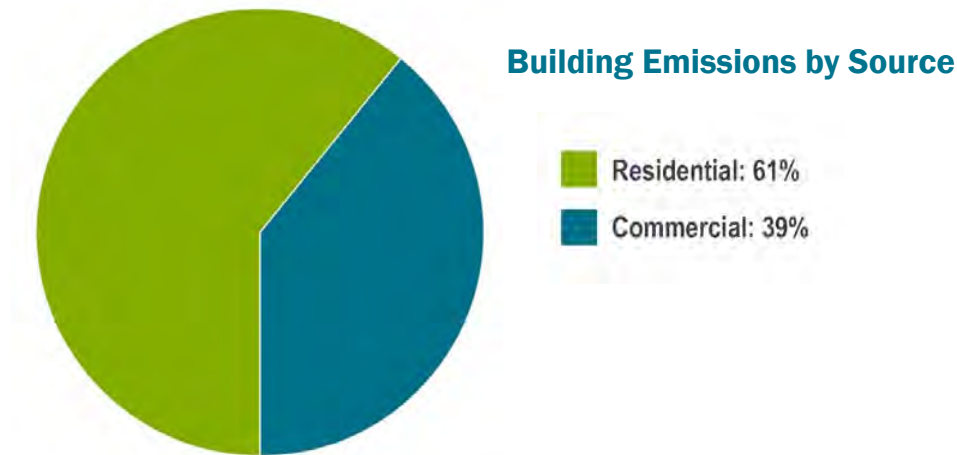
## REPAIR AND DECARBONIZE HOMES AND BUSINESSES

As of 2019, Michigan's buildings accounted for almost 18 percent of the state's total GHG emissions, the third highest emitting sector after the power and transportation sectors. While Michigan's buildings use a significant amount of electricity for lighting, appliances, air conditioning, ventilation, and other purposes, those emissions are accounted for in the electric generation sector. Emissions related to the built environment are primarily due to use of heating fuels such as natural gas, propane, and oil.

In addition to its pivotal role in achieving our climate goals, investing in our building stock will help lower utility and other costs for working families and small businesses, make our homes and workplaces healthier, and expand economic opportunities across the state. Decarbonizing our buildings will require baseline investments in repairing Michigan's homes; stronger requirements, incentives, and financing options for energy efficiency and waste reduction; and evaluation and adoption of innovative home heating alternatives, including electrification in immediately cost-effective use cases.

### Key Strategies

- **Heating Michigan homes and businesses** - Reduce emissions related to heating Michigan homes and businesses 17 percent by 2030. Focus on both public and private-sector investments and targeted efficiency and assistance programs to reduce the energy burden for low-income residents.
- **Clean financing opportunities** - Explore programs, financing options, and public funding opportunities - including the allocation of funds to the state's nonprofit green bank, Michigan Saves - to help families, small businesses, and schools invest in clean energy projects from weatherization to renewables and building decarbonization. Adopt and promote utility on-bill financing and property assessed clean energy programs (PACE). Identify sources of consistent, ongoing funding to address homes that are ineligible for weatherization assistance.
- **Building codes and climate readiness** - Adopt the 2021 Model Energy Code with provisions to support electric vehicle charging and consider incorporation of additional climate mitigating solutions such as energy storage, renewable energy, and building decarbonization.
- **Energy waste reduction programs** - Increase utilization of cost-effective opportunities to reduce energy waste. Achieve at least 2% annual electric energy efficiency savings by increasing the current energy waste reduction target for electric utilities and maintaining the corresponding incentives for exceeding statutory minimums. Restore the energy waste reduction target for municipal and cooperative electric utilities. Increase energy waste reduction (EWR) for natural gas utilities to a minimum of 1.5% annual savings with enhanced cost-effective incentives for exceeding statutory minimums. Work to ensure energy efficiency is on a level playing field with supply-side resources (i.e., power generation) in the MPSC integrated resource planning (IRP) process which guides the financial investments of Michigan utilities. Explore additional pathways to reduce energy demand and energy burden.
- **Incentives for energy efficient appliances** - Establish incentives for the sale of electric appliances that yield immediate energy and cost savings, particularly for low-income Michiganders.
- **Evaluate gas system regulatory and policy options** - Undertake a pathway analysis to assess options to reduce carbon intensity in the built environment.



## Background

To reach our 2030 goals of reducing emissions relating to heating Michigan homes and businesses 17 percent by 2030, Michigan must reduce end-use emissions related to heating Michigan homes and businesses by approximately three percent per year from now to 2030. We will accomplish this objective through investments in energy conservation, energy efficiency, smart consumption, cogeneration, and replacing traditional fossil fuel use with cost-effective technologies that rely on electricity and alternatives like renewable natural gas and hydrogen.

Half of Michigan homes are less than 50 years old. With adequate care and maintenance, most will remain in use through and beyond 2050. While the other half of Michigan homes are more than 50 years old, most can be expected to last another 50 years or more with modest investments. However, many of these buildings are inefficient and rely on fossil fuels for heating and appliances like gas stoves. They will require significant upgrades to be fully decarbonized.

Energy efficiency and weatherization investments targeted at Michigan's most inefficient buildings will drive significant investments in Michigan's most disadvantaged communities. Unfortunately, not every home is ready for energy efficiency and weatherization upgrades. Many of Michigan's most inefficient buildings need a new roof or upgrades to remove carbon monoxide from the home before they can qualify for many available funding programs. In fact, 25 percent of all weatherization projects across the state are deferred due to structural challenges. This barrier is even higher in older communities like Detroit where deferral reaches nearly 75%. Michigan must increase investments in home repairs and streamline access to energy efficiency and weatherization funding programs for communities with aging housing stocks. This is a pre-requisite to decarbonizing our building sector and achieving our short- and long-term GHG reduction goals.

## Reduce energy waste

Under [Michigan law](#), electricity providers must achieve annual EWR of one percent per year (based on total annual retail sales of the prior 12 months) and gas providers must hit 0.75 percent. In addition, Michigan law provides financial incentives for energy providers to meet or exceed those standards. In just over a decade, these policies have resulted in a lifetime savings of [nearly \\$1.2 billion for electric and gas customers](#). When it comes to reducing emissions—and saving money for Michigan families and businesses—it is hard to get more bang for the buck than cutting energy use.

Building from their success thus far, Michigan should strengthen existing EWR programs for investor-owned utilities – doubling the energy waste reduction target for electricity to two percent and bumping it up to 1.5 percent for natural gas. The state should also restore the EWR targets for municipal and cooperative electric utilities. In taking these steps, we must create and leverage incentives for over-performance and encourage robust consideration of EWR alongside power generation in IRPs.

### **Building new, clean buildings**

While Michigan’s existing homes and buildings will account for most of the GHG emissions in this sector from now through 2030, we must work to ensure that all new residential and commercial buildings are as efficient as possible, use materials with a low carbon footprint like mass timber, and prepare for new technologies. To help make this possible, Michigan must adopt the 2021 Model International Energy Conservation Code for new buildings. Michigan should also expand on the model code to include provisions to support electric vehicle charging and consider the incorporation of additional climate mitigating solutions such as energy storage, renewable energy, and building decarbonization.

### **Rethink how we heat our buildings**

Moving forward, Michigan should consider and evaluate alternatives to current strategies for heating Michigan’s buildings. According to research from [Rewiring America](#), at least 39 percent of Michigan households—or 1.5 million households—could save a total of \$710 million a year on energy bills if they were using modern heat pump space heaters and heat pump water heaters instead of their current appliances, which use electric resistance, fuel oil, or propane. That’s an average savings per household of \$460 each year. Half of the households with immediate savings potential are considered low- and moderate-income. The switch to electric heating and other appliances may also yield health benefits, such as helping to reduce the risk of respiratory symptoms associated with gas stove use. To make heating less carbon-intensive, Michigan should establish incentive programs for electric appliances and heat pumps for use-cases that will save customers money today, with an emphasis on energy burden relief for low-income residents.

To complement immediate policy actions, the Plan recommends the state undertake a pathway analysis to assess options to achieve carbon neutrality from natural gas production, transmission, distribution, compression, storage, and end uses in a least-cost manner. This analysis should consider a full range of options for decarbonizing natural gas end uses, including energy efficiency, electrification, fuel switching to renewable natural gas and hydrogen, and other potential opportunities.

### **Increase financing**

To facilitate home repairs, energy efficiency investments, and electrification, Michigan should also expand direct state investments and customer-facing financing options. By supporting programs like on-bill financing and property assessed clean energy (PACE), Michigan can create easier access to capital at better terms for customers and attract more private sector capital to the building decarbonization challenge.



## DRIVE CLEAN INNOVATION IN INDUSTRY

As of 2019, Michigan's industrial sector accounted for 15 percent of the state's total GHG emissions, the 4th highest emitting sector after the buildings and housing sector. While aggregated together in tracking emissions, the state's industrial sector is remarkably diverse, and makes products like chemicals, iron, steel, cement and food using specific manufacturing processes that can cause on-site GHG emissions, often require a lot of power, and/or involve GHG emissions in their supply chains.

Decarbonizing these sectors will require process-specific solutions with a focus on advancing research and development, improving facility efficiency, using cleaner products and fuels, and developing new markets for byproducts.

### Key Strategies

- **Buy clean, buy Michigan** – Strengthen public and private-sector procurement programs to favor the use of low-carbon and circular-economy products and identify opportunities to support disadvantaged businesses in procurement. Encourage the production and purchase of materials made by Michigan workers.
- **Recycling and waste** – Triple the state's recycling rate to 45 percent and cut food loss and waste in half by 2030. Expand on efforts like 'Next Cycle' to develop markets for recycled materials.
- **Shared clean industrial innovation** – Encourage clean innovation hubs to collaborate on the development and deployment of new, cleaner manufacturing technologies and reduce emissions from hard to decarbonize industries. Work to ensure that Michigan communities impacted by industrial development and operations are meaningfully engaged in the siting, construction, and operation of clean innovation hubs.
- **Clean industry process improvements** – Provide incentives and technical assistance to advance the energy efficiency and other process improvements necessary to achieve carbon neutrality in the industrial sector by 2050. Deploy combined heat and power (CHP) in new facilities and convert existing facilities to renewable energy or lower-carbon fuels such as biogas, renewable natural gas or biomethane, and clean hydrogen.
- **Carbon capture, utilization, and sequestration** – Explore the use of carbon capture, utilization, and sequestration in industrial applications where eliminating the use of fossil fuels is impossible or cost-prohibitive and for entities attempting to go carbon negative in their operations.

## Background

Michigan's industrial sector represents one of the state's greatest strengths on the path to carbon neutrality. Michigan has the [5th largest](#) advanced manufacturing workforce in the country, with more than 65,000 workers employed in that sector in 2019. The state is a national leader for employment in industries related to [Industry 4.0](#) and automation. Of the top 100 automotive suppliers to North America, 96 have a presence in Michigan and [71](#) are headquartered here. The state is home to nearly [19% of all U.S. auto production](#), more than any state in the nation.

This unparalleled industrial heritage and the technological know-how of our workforce positions Michigan well to develop and manufacture the next generation(s) of innovative products that will be used in every sector of our economy to unlock new decarbonization strategies. To make Michigan the trailblazing home for the low-carbon inventions of tomorrow—and create the corresponding opportunities for sustained economic growth and job creation—the state will need innovative market development and regulatory programs and strong financial incentives.

In addition to manufacturing the products needed to decarbonize other sectors, Michigan's industrial sector has already taken significant steps in reducing GHG emissions from its operations. Between 2005-2018, the industrial sector cut their emissions by [5.9 million metric tons](#) – or more than 23 percent. Additional analysis suggests that the industrial sector has the potential to reduce their annual emissions by [an additional 5.7 million metric tons](#) by 2030 – a reduction of more than 45 percent when compared to 2005 levels.

## Efficient facilities

Energy efficiency is a vital tool that can help Michigan's industrial sector reduce GHG emissions while keeping energy costs reasonable. Importantly, industrial energy efficiency and process improvements may be able to reduce local air pollution in communities located near industrial facilities and can create new workforce opportunities conducting energy audits and implementing the energy saving strategies they identify.

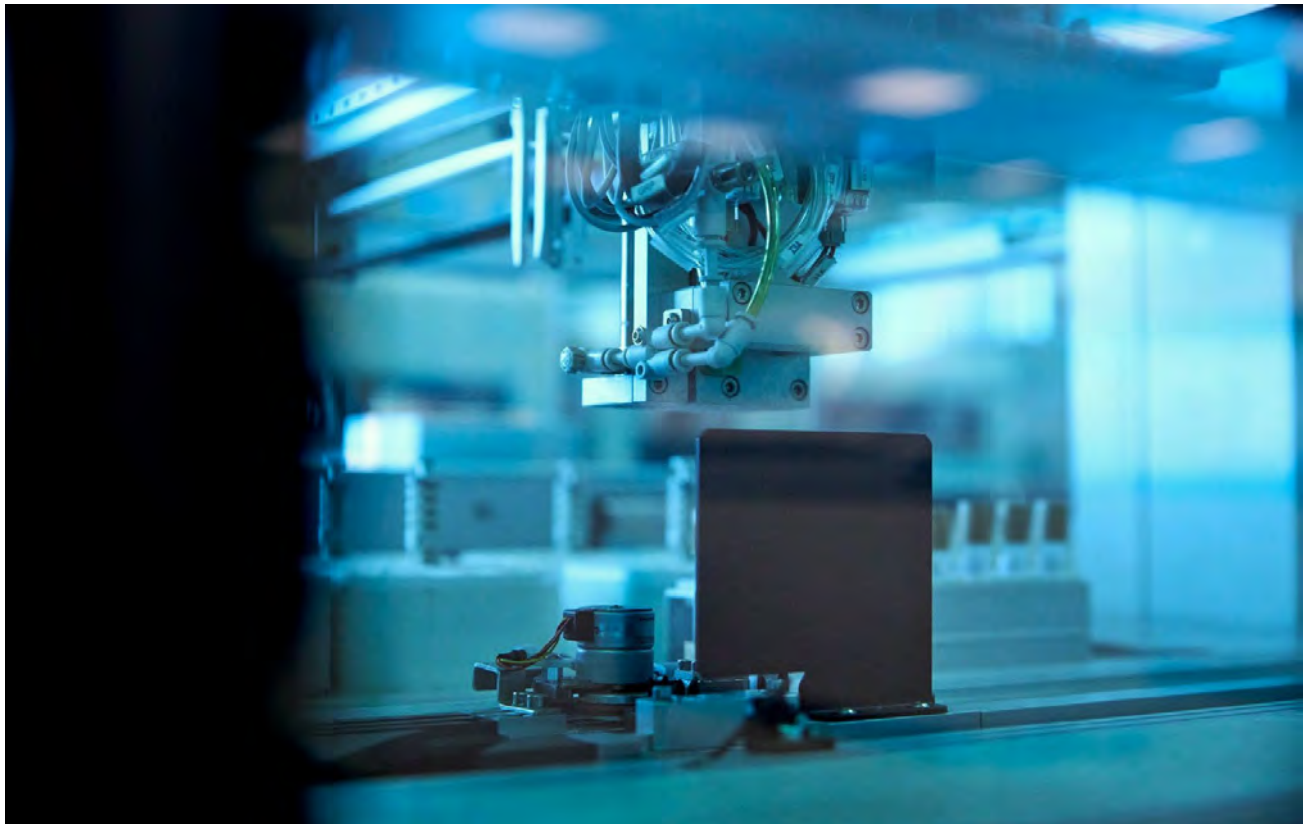
A key efficiency opportunity exists around CHP, which is a process that takes excess heat from an industrial process or facility and uses it to generate electricity. CHP is the most fuel-efficient way to produce and utilize both electric and thermal energy from a single fuel source. In 2018, the Michigan Energy Office released its [CHP Roadmap for Michigan](#), which recommended an optimal level of additional CHP deployment in Michigan ranging from 722 MW to 1,014 MW by 2030. The [next wave of CHP applications](#) will enable deeper decarbonization of the industrial sector through the use of renewable energy or lower-carbon fuels such as biogas, renewable natural gas or biomethane, and hydrogen.

### Cleaner products

Michigan is well-positioned to grow its circular economy—a systems approach that emphasizes growing markets for recyclable materials so they are (re)used by Michigan workers and business to make new products, rather than taken to landfills or other disposal facilities. For example, EGLE’s [‘Next Cycle’](#) program works with businesses to incubate ideas that grow Michigan’s recycled materials supply chain and end markets. The Plan identifies a number of opportunities to further spur market demand for cleaner products, such as lower-carbon cement for use in infrastructure projects. It also calls for expanding public and private sector clean procurement programs.

### Clean innovation hubs

While some decarbonization solutions already exist today, many are still waiting to be innovated. As home to many energy-intensive industries, Michigan is well-positioned to lead the way on industrial decarbonization solutions. Clean innovation hubs can help Michigan’s industrial sector achieve GHG emissions reductions as cost-effectively as possible through shared infrastructure, the strategic co-location of industrial facilities, and the efficient use of materials and energy streams. Individual clean innovation hubs could focus, for example, on hydrogen technologies or electric vehicle battery recycling. Safeguards must be put in place to address any public health and environmental justice concerns with these facilities. Potentially impacted communities should have the opportunity for adequate consultation in the siting, construction, and operations of any innovation hub.



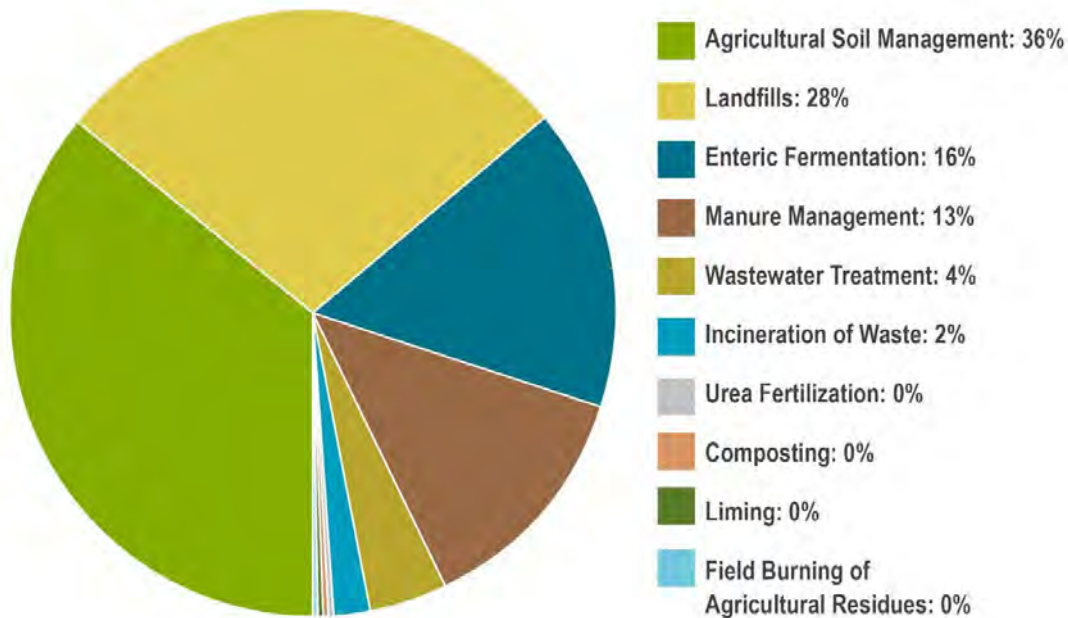
## PROTECT MICHIGAN'S LAND AND WATER

As of 2019, Michigan's natural and working lands accounted for nine percent of the state's total GHG emissions, contributing the smallest percentage of overall emissions from an individual sector. These emissions come primarily from agricultural practices and land-use changes. To drive decarbonization and sequester carbon in Michigan's natural and working lands sector, it will be crucial to protect and conserve Michigan's natural resources and support innovative solutions in agriculture.

### Key Strategies

- **30 x 30** – As a part of the national 'America the Beautiful' initiative, protect 30 percent of Michigan's land and water by 2030 to naturally capture GHG emissions, while maintaining and improving recreational opportunities for all Michiganders, expanding access in disproportionately impacted communities, and protecting biodiversity.
- **Wetlands, waters, soils, forests** – Avoid land-use conversion that causes a net increase in GHG emissions and prioritize land uses that reduce GHG emissions. Protect and restore existing wetlands and waterways and create new wetlands where appropriate. Adopt policies to protect the state's soils and enhance their capacity to capture and store carbon. Maintain and develop healthy forests across public and private lands. Support and promote tools that expand the use of the mass timber as a sustainable building material.
- **Treaty rights** – As conservation efforts move forward, the state will not interfere with treaty rights, treaty resources, and tribal cultural resources and will consult with Tribal Nations. Conservation efforts must respect the exercise of treaty rights.
- **Farm management and practices** – Develop initiatives to support farmers in adopting best management practices to improve soil health, store carbon, and utilize other greenhouse gas emissions, while also protecting water quality. Create programs to catalyze and accelerate the transition to cleaner technologies like electric and hydrogen fuel-cell farm equipment.
- **Michigan grown products** – Fund programs like the 'Buy Michigan Agriculture Campaign' to encourage the purchase of Michigan grown and raised products, address food insecurity challenges, and counter supply chain issues.

## Agriculture and Waste Emissions by Source



### Background

From birdwatching, hunting, and camping to the timber and forest products that are used in our homes and businesses, our lands, waters, and forests are essential components of what makes Michigan, “Pure Michigan.”

The lands and waters we call Michigan today are the ancestral territories of the Anishinaabe, who have lived in the State of Michigan from before recorded history to present day. The Anishinaabe people’s commitment to this place should encourage us to be better stewards of the land we inhabit and the waters on which we depend.

The Michigan Department of Natural Resources manages [4.6 million acres of public lands](#), 3.86 million of which are forested, and the state contains roughly [5.5 million acres of wetlands](#). Michigan is also home to over 50,000 farms. If protected and appropriately managed, Michigan’s natural and working lands can store and sequester carbon and offer additional benefits including limiting water runoff pollution, providing habitats that support biodiversity, and reducing the impacts on Michigan communities from more frequent and intense flooding, extreme heat, and other effects of climate change. These lands are critical to our economy and the health of all Michiganders.



## Michigan's natural resources and land use

Michigan's [forests currently store](#) approximately 537 million tons of live tree carbon and 2,045 million tons of total forest ecosystem carbon, and they continue to sequester additional carbon from the atmosphere with each passing day. Sustainable forest management is key to maintaining and expanding the role of forests in reducing carbon emissions – and avoiding the loss of important carbon sinks that would make Michigan's path to carbon neutrality even more challenging.

In addition, sustainable forestry can encourage responsible sourcing and recycling of forest products. Building out a sustainable forestry and forest product industry can create thousands of good-paying jobs for Michiganders, capture new economic development opportunities, and provide sustainable building materials like mass timber.

Many of the state's powerful natural carbon sinks have been developed or converted and lost their natural ability to store carbon, increasing net GHG emissions. Wetlands, in particular, are important carbon sinks and stocks. Building out green waterway infrastructure, like constructed wetlands, can yield both climate adaptation and mitigation benefits. This Plan recommends avoiding further land-use conversions that increase GHG emissions and stewarding Michigan's natural resources by implementing land-use strategies that reduce GHG emissions in partnership with Michigan's tribal governments.

The federal government signed several treaties with tribal nations in Michigan, which reserved hunting and fishing rights for tribal members. Working with and supporting tribal nations will be an essential component of managing natural and working lands in a way that respects and does not interfere with treaty rights, treaty resources, and tribal cultural resources.



## Soil health and innovation in agriculture

Michigan is the second most agriculturally diverse state in the country. The state is [home to nearly 50,000 farms](#), spanning over nine million acres of agricultural land. These lands have an opportunity to sequester carbon, but many agricultural practices also emit it. This Plan recommends solutions to implement best practices for managing working lands to restore soil health and store carbon, provide low-carbon equipment to farmers, increase access to locally sourced agriculture, and reduce food waste.

Promoting climate-smart strategies like cover crops, conservation tillage, and precision agriculture can improve soil health, store carbon, improve water quality, and reduce fertilizer needs. Biochar and compost also have the opportunity to reduce both food waste and reliance on synthetic fertilizers. Innovative animal feed mixes and additives can be used to reduce GHG emissions from livestock.

Across the state, there are communities that lack access to healthy, high-quality food. As we transform our agricultural sector to mitigate and adapt to climate change, we must also take that opportunity to ensure that everyone can get the food they need to live healthy lives. Supporting Michigan-grown agriculture, urban agriculture, and farmer's markets by funding programs like the 'Buy Michigan Agriculture Campaign' can promote healthy local food systems and reduce emissions from transporting food.

While some solutions are apparent for Michigan's working lands, additional funding opportunities, research, and technological advancements will be necessary to understand how to fully decarbonize this sector in a way that balances the needs of farmers, ecosystems, and all Michiganders.





## LEADING BY EXAMPLE IN STATE GOVERNMENT

State governments have a variety of tools in their purview to address climate change. For example, state agencies use energy, procure or purchase vehicles and other goods/services, and make a wide variety of other investments in our communities and economy. Decisions and actions in these and other areas are opportunities for the State of Michigan to show the way to carbon neutrality.

In 2019, the governor's office launched an interdepartmental workgroup to identify opportunities for state government to lead by example and use administrative powers to reduce GHG emissions. This work focused on how the state could incorporate climate mitigation into existing state programs and identify initiatives that departments could pursue to accelerate the transition toward carbon neutrality. This effort demonstrated that every state department – from the Department of Natural Resources to the Department of Treasury – has an opportunity to act on climate.

In response to this work, Governor Whitmer created new offices and initiatives to help strengthen climate action across state government, including the Energy Transition Impact Project at the Department of Treasury and the Office of Future Mobility and Electrification at the Department of Labor and Economic Opportunity (LEO). The leaders of these programs collaborate closely with their colleagues in the Office of Climate and Energy and Office of Environmental Justice Public Advocate, which Governor Whitmer created at EGLE as one of her first acts in office to lead carbon reduction, just transition, and environmental justice efforts.



Solar Panels at Oden State Fish Hatcher – *photo courtesy of the Michigan DNR*

This focus and planning on climate—along with the structuring of climate work directly into state agency organizational charts—has led to bold actions by the State of Michigan to reduce GHG emissions. While not an exhaustive list, the following highlights some examples of the state leading by example.



## LEADING BY EXAMPLE IN STATE OPERATIONS

To reduce GHG emissions in State of Michigan operations, the Whitmer administration and state agencies have:

- Signed agreements to power state-owned facilities with 100 percent renewable energy by 2025.
- Committed to carbon neutrality in state-owned buildings by 2040.
- Pledged to reduce energy usage in state-owned facilities 40 percent by 2040.
- Established a \$5 million Energy Efficiency and Green Revolving Fund to expand renewable energy and energy efficiency projects at state facilities (and proposed an expansion of this investment in the FY 2023 budget proposal).
- Developed a plan to responsibly site solar across state-owned properties.
- Upgraded state systems to deploy more efficient water use (and reuse) techniques, saving energy and thousands of gallons of water per year.
- Launched the nation's first carbon sequestration and carbon market program on state owned forest land.
- Committed to electrify the state's vehicle fleet, starting with a \$10 million FY 2023 budget proposal.
- Required consideration of vendor environmental track records in the state's procurement and purchasing decisions.
- Required all state facilities to offer recycling services.
- Developed a toolkit for state agencies to review sustainability projects on state properties and ensure easy access to information on how to initiate eco-friendly practices.
- Launched a state employee education campaign around sustainability.
- Invested in backup power for all state-owned pumping stations to reduce freeway flooding events in Southeast Michigan.

## LEADING BY EXAMPLE IN STATE BUDGETS

Each of the budgets Governor Whitmer has signed so far have delivered millions of dollars for strategies and investments to address climate change. Most recently, Governor Whitmer proposed an [FY 2023 executive recommendation](#) that included over half a billion dollars in climate, advanced mobility, and clean energy related funding. These proposals ranged from investments in the state green bank and building out electric vehicle charging infrastructure to the reforestation of native trees and grants to communities for climate-resilient infrastructure.

## LEADING BY EXAMPLE IN STATE PROGRAMS

State agencies are also showing the way to carbon neutrality by developing new programs—and reshaping existing ones—to jumpstart progress in implementing the strategies in this Plan.

### Commit to Environmental Justice and Pursue a Just Transition

- EGLE developed a Michigan-specific EJ Screening tool that provides maps and data to help Michigan move toward environmental equity. It allows users to identify where populations are more vulnerable and what challenges communities face. EGLE is also supporting the Michigan Public Service Commission (MPSC) in considering environmental justice and health impacts as a part of the utility integrated resource plan process.
- The Department of Health and Human Services published a *Climate and Health Adaptation Planning Guide for Michigan Communities* to help local units of government and their residents integrate climate and health concepts into existing community planning and decision making.

### Clean the Electric Grid

- The MPSC launched MI Power Grid, a multi-year stakeholder process to maximize the benefits of clean, distributed energy resources for Michigan residents and businesses.
- The Michigan Department of Agriculture and Rural Development (MDARD) developed a policy allowing farmers to rent land for large scale solar operations while maintaining preservation of farmland by suspending and extending agreements for an equivalent number of years to properties enrolled in the PA 116 program.

### Electrify Vehicles and Increase Public Transit

- The Office of Future Mobility and Electrification within LEO has led several projects to promote electric vehicle adoption and eliminate range anxiety associated with the availability of electric vehicle charging infrastructure.
- The Michigan Department of Transportation (MDOT) completed a Transportation Asset Management Plan which included analysis of risks to the department related to climate change. It has also supported external initiatives like the Southeast Michigan Council of Government's climate resiliency and flooding mitigation study to determine which infrastructure assets in southeast Michigan—including roads, bridges, culverts, and pump stations—are most at risk for flooding

### Repair and Decarbonize Homes and Businesses

- The Michigan State Housing Development Authority (MSHDA) within LEO included a Green Policy within their Qualified Allocation Plan to require all its housing projects to achieve a green building certification and to add incentives for projects to achieve higher levels of sustainability commitments and energy efficiency. MSHDA's 2022 Statewide Housing Plan also includes focuses on environmental justice in housing development and rehabilitation.

## Protect Michigan's Land and Water

- The DNR incorporated climate mitigation as a key pillar in their Public Land Strategy to ensure the department identified appropriate strategies for emerging, climate-based threats to natural resources, and launched the nation's first carbon sequestration and carbon market program on state forest land.

## Drive Clean Innovation in Industry

- The Michigan Economic Development Corporation (MEDC) within LEO has started integrating Michigan's climate goals into its business attraction efforts and has adjusted their focus to strategic industries that support the transition to a clean energy future, including energy storage businesses, electrified vehicle manufacturers, and companies that perform research and development in these sectors.



Governor Gretchen Whitmer and EGLE Director, Liesl Clark speak at an Earth Day Event.

**This broad and deep State of Michigan leadership will help spur the state's economy and catalyze rapid progress toward achieving carbon neutrality by 2050.**

## CONCLUSION

The realities of the climate crisis are already directly impacting Michiganders and present our state with both an existential challenge and a compelling opportunity. If we fail to act with the urgency required, the impacts of climate change will likely only get worse, disproportionately affecting those who have long borne the brunt of environmental injustice. Yet a better path exists—a bold and strategic response to the climate crisis that will reward our state with enhanced economic opportunities, good-paying sustainable jobs, affordable and reliable energy for all, and clean air and water for every Michigander.

The steps to achieving this vision are within reach, though urgent action is needed. This MI Healthy Climate Plan lays out in detail the steps we need to take immediately to achieve a 52 percent reduction in GHG emissions by the end of this decade, including efforts to clean the electric grid, electrify vehicles and increase public transit, repair and decarbonize homes and businesses, drive clean innovation in industry, and protect Michigan lands and water. As we drive GHG reductions in each of those areas, the Plan calls on us to pursue environmental justice every step of the way and commit to a just transition to a carbon neutral economy for all Michigan workers and communities.

No less importantly, the Plan identifies the equally urgent actions needed now to fully decarbonize Michigan's economy by 2050, including areas where additional work and study are needed for harder-to-decarbonize sectors including buildings and housing, industry, and agriculture.

With bold leadership by example from state government and every Michigan resident and business playing their parts, we can – together – build a more equitable, just, healthy, and prosperous future and ensure that the benefits of this clean energy transition are enjoyed by all Michiganders.

## IMPLEMENTATION

The State of Michigan is committed to implementing the MI Healthy Climate Plan. As directed by the Executive Order calling for this Plan, the Office of Climate and Energy within EGLE will oversee its implementation in concert with state departments and agencies, tribal and local governments, and key stakeholders. The Council on Climate Solutions and Michigan Advisory Council on Environmental Justice will provide advice, feedback, and guidance along the way. And, as required by the Order, EGLE will submit publicly available annual reports updating all 10 million Michiganders on our progress.



## APPENDICES

- [Workgroup summaries of Key Recommendations presented to the Council on Climate Solutions](#)
- [Michigan Advisory Council on Environmental Justice recommendations to the Council on Climate Solutions and the State of Michigan.](#)

DTE Electric Company  
One Energy Plaza, 1635 WCB  
Detroit, MI 48226-1279



Andrea E. Hayden  
(313) 235-9449  
andrea.hayden@dteenergy.com

April 3, 2023

Ms. Lisa Felice  
Executive Secretary  
Michigan Public Service Commission  
7109 W. Saginaw Highway  
Lansing, MI 48917

Re: In the matter on the Commission's own motion, to provide electric power reliability information in its annual power quality report  
MPSC Case No. U-16065

In the matter on the Commission's own motion to investigate the responses of CONSUMERS ENERGY COMPANY and DTE ELECTRIC COMPANY to recent storm damage in their service territories.  
MPSC Case No. U-17542

Dear Ms. Felice:

Attached for electronic filing in the above captioned matter is DTE Electric Company's January 1, 2022 through December 31, 2022 Report to the Michigan Public Service Commission Regarding Electric Distribution System Power Quality.

Very truly yours,

Andrea E. Hayden

Digitally signed by Andrea E.  
Hayden  
Date: 2023.04.03 13:57:19 -04'00'

Andrea E. Hayden

AEH/cdm  
Attachment



Reliability Performance and Power Quality Resolution Process  
DTE Electric Report for 2022

**Background**

On September 5, 2009, the Michigan Public Service Commission issued an Opinion and Order in Case No. U-16065, in which it directed that the two major Michigan utilities 1) provide information related to SAIFI, CAIDI, and SAIDI reliability indices with and without major events, on a rolling five year average basis, using the industry standard IEEE method of calculation, and 2) file an annual power quality investigation report which contains data on all primary customer power quality investigations conducted in the past year for end-use customers, derived from their power quality meters, and the outcome of each investigation. This report contains the DTE Electric January 1, 2022 through December 31, 2022 results and compliance status per those requirements.

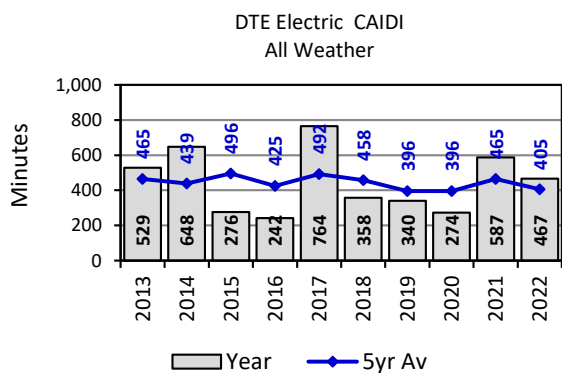
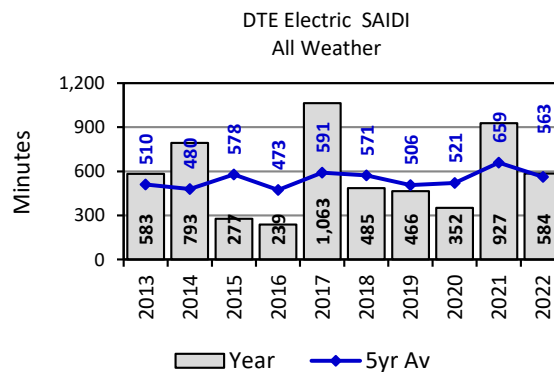
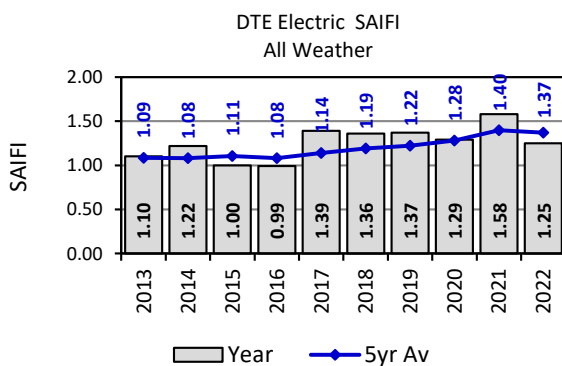
On December 4, 2014, the Michigan Public Service Commission issued an Order in Case No. U-17542, in which, in part, increased reporting requirements for Consumers Energy Company and DTE Electric Company relative to ongoing dockets Case No. U-16065 and Case No. U-12270. The additional information is to be provided no later than April 2 of each year. The additional reporting requirements are:

1. a list of their 10 worst performing circuits for the prior year in terms of both SAIDI and SAIFI;
2. for each of the 10 worst performing circuits, the utility shall provide the following information: (a) SAIDI and SAIFI excluding major events for the year, (b) circuit name, number and location, (c) length of circuit (miles), (d) number of customers served, (e) substation name, (f) last circuit trim, (g) list of outages and causes, and (h) corrective action plan to improve performance;
3. number of customers experiencing multiple interruptions (CEMI) reporting for indices  $CEMI_0$  through  $CEMI_{10+}$ ; and
4. number of customers experiencing long interruption durations (CELID) reporting for indices  $CELID_{60hrs}$  and  $CELID_{8hrs}$  (excluding catastrophic events).

## Reliability Performance and Power Quality Resolution Process DTE Electric Report for 2022

### Reliability Performance – SAIFI, SAIDI, CAIDI – All Weather

|      | All Weather |         |           |         |           |         |
|------|-------------|---------|-----------|---------|-----------|---------|
|      | SAIFI       |         | SAIDI     |         | CAIDI     |         |
| Year | Each Year   | 5yr Avg | Each Year | 5yr Avg | Each Year | 5yr Avg |
| 2013 | 1.10        | 1.09    | 583       | 510     | 529       | 465     |
| 2014 | 1.22        | 1.08    | 793       | 480     | 648       | 439     |
| 2015 | 1.00        | 1.11    | 277       | 578     | 276       | 496     |
| 2016 | 0.99        | 1.08    | 239       | 473     | 242       | 425     |
| 2017 | 1.39        | 1.14    | 1,063     | 591     | 764       | 492     |
| 2018 | 1.36        | 1.19    | 485       | 571     | 358       | 458     |
| 2019 | 1.37        | 1.22    | 466       | 506     | 340       | 396     |
| 2020 | 1.29        | 1.28    | 352       | 521     | 274       | 396     |
| 2021 | 1.58        | 1.40    | 927       | 659     | 587       | 465     |
| 2022 | 1.25        | 1.37    | 584       | 563     | 467       | 405     |

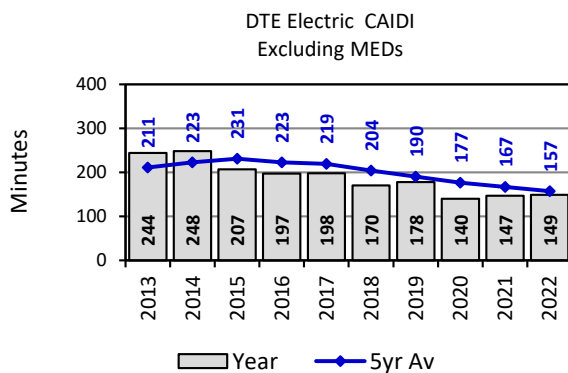
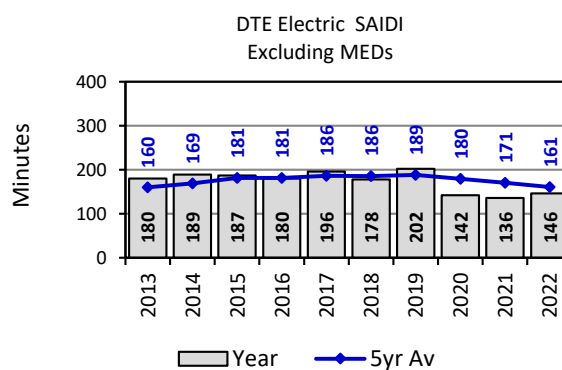
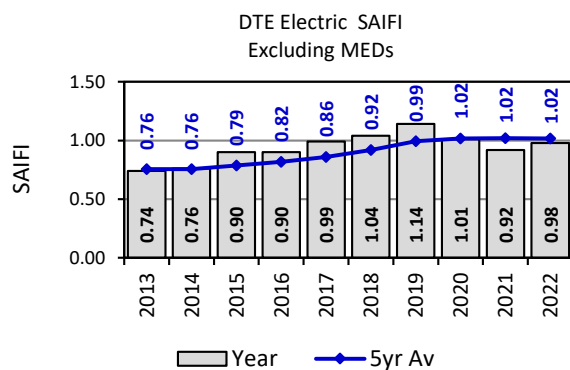




## Reliability Performance and Power Quality Resolution Process DTE Electric Report for 2022

### Reliability Performance – SAIFI, SAIDI, CAIDI – Excluding MEDs

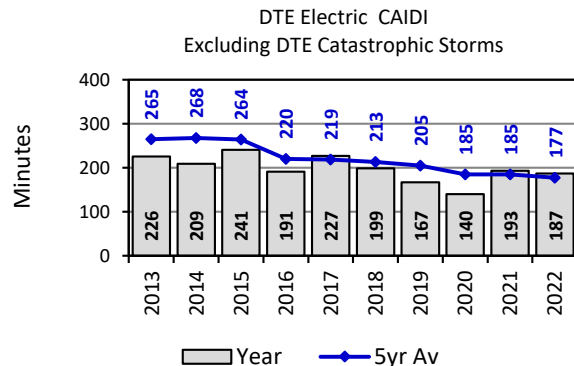
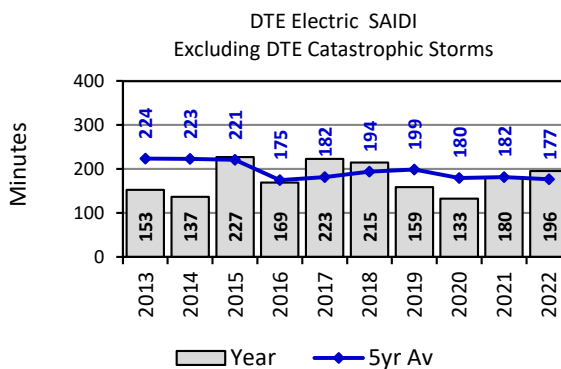
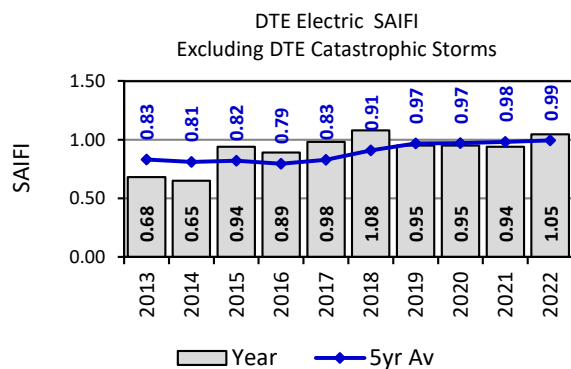
|      | Excluding MEDs per IEEE 1366-2003 |         |           |         |           |         |
|------|-----------------------------------|---------|-----------|---------|-----------|---------|
|      | SAIFI                             |         | SAIDI     |         | CAIDI     |         |
| Year | Each Year                         | 5yr Avg | Each Year | 5yr Avg | Each Year | 5yr Avg |
| 2013 | 0.74                              | 0.76    | 180       | 160     | 244       | 211     |
| 2014 | 0.76                              | 0.76    | 189       | 169     | 248       | 223     |
| 2015 | 0.90                              | 0.79    | 187       | 181     | 207       | 231     |
| 2016 | 0.90                              | 0.82    | 180       | 181     | 197       | 223     |
| 2017 | 0.99                              | 0.86    | 196       | 186     | 198       | 219     |
| 2018 | 1.04                              | 0.92    | 178       | 186     | 170       | 204     |
| 2019 | 1.14                              | 0.99    | 202       | 189     | 178       | 190     |
| 2020 | 1.01                              | 1.02    | 142       | 180     | 140       | 177     |
| 2021 | 0.92                              | 1.02    | 136       | 171     | 147       | 167     |
| 2022 | 0.98                              | 1.02    | 146       | 161     | 149       | 157     |



## Reliability Performance and Power Quality Resolution Process DTE Electric Report for 2022

### Reliability Performance – SAIFI, SAIDI, CAIDI – Excluding DTE Electric Catastrophic Storms

| Year | Excluding DTE Electric Catastrophic Storm Days |         |           |         |           |         |
|------|------------------------------------------------|---------|-----------|---------|-----------|---------|
|      | SAIFI                                          |         | SAIDI     |         | CAIDI     |         |
|      | Each Year                                      | 5yr Avg | Each Year | 5yr Avg | Each Year | 5yr Avg |
| 2013 | 0.68                                           | 0.83    | 153       | 224     | 226       | 265     |
| 2014 | 0.65                                           | 0.81    | 137       | 223     | 209       | 268     |
| 2015 | 0.94                                           | 0.82    | 227       | 221     | 241       | 264     |
| 2016 | 0.89                                           | 0.79    | 169       | 175     | 191       | 220     |
| 2017 | 0.98                                           | 0.83    | 223       | 182     | 227       | 219     |
| 2018 | 1.08                                           | 0.91    | 215       | 194     | 199       | 213     |
| 2019 | 0.95                                           | 0.97    | 159       | 199     | 167       | 205     |
| 2020 | 0.95                                           | 0.97    | 133       | 180     | 140       | 185     |
| 2021 | 0.94                                           | 0.98    | 180       | 182     | 193       | 185     |
| 2022 | 1.05                                           | 0.99    | 196       | 177     | 187       | 177     |



## Reliability Performance and Power Quality Resolution Process DTE Electric Report for 2022

In 2022, DTE Electric experienced 28 weather events: one was a catastrophic storm interrupting greater than 10% of the customer base (MPSC catastrophic criteria), nine were smaller storms and eighteen were gray sky days. In total DTE Electric was in restoration mode for 72.1 days (6.0 for MPSC catastrophic storms and 66.1 days for smaller storms and gray sky days).

### Major Event Days

In 2022, there were a total of seven Major Event Days (MEDs). Two occurred during the largest, catastrophic storm, which met the MPSC criteria, and that occurred in August/September and the remaining five occurred during weather that can be described as DTE non-catastrophic storms and/or normal conditions.

| Storm Criteria | Customers Interrupted | Storm Start Date/Time | Storm Finish Date/Time | Days in Storm Mode | # MEDs | MED Dates  |
|----------------|-----------------------|-----------------------|------------------------|--------------------|--------|------------|
| MPSC           | 454,069               | 8/29/2022 16:00       | 9/4/2022 17:00         | 6.0                | 2      | 8/29, 8/30 |

| Year | # MEDs During DTE Catastrophic Storms | # MEDs During DTE Non-Catastrophic Storms And Normal Conditions |
|------|---------------------------------------|-----------------------------------------------------------------|
| 2013 | 9                                     | 1                                                               |
| 2014 | 9                                     | 0                                                               |
| 2015 | 1                                     | 2                                                               |
| 2016 | 2                                     | 0                                                               |
| 2017 | 6                                     | 3                                                               |
| 2018 | 4                                     | 5                                                               |
| 2019 | 4                                     | 2                                                               |
| 2020 | 7                                     | 1                                                               |
| 2021 | 16                                    | 6                                                               |
| 2022 | 2                                     | 5                                                               |

Reliability Performance and Power Quality Resolution Process  
DTE Electric Report for 2022

**Causes of Forced Interruptions**

AMI meter data does not include interruption cause codes. To determine the cause, an effort is made to associate each AMI interruption event with the InService Outage Management System (OMS) event in which the cause of the interruption is recorded by the crew. However, not all AMI meter events align with the data included with InService OMS events. The percentages of interruption events by cause in this report are based on those events where the associated cause is known.

The most common cause of forced customer interruptions in 2022 was tree interference.

| Conditions          | Forced Interruptions by Cause    |           |      |       |           |
|---------------------|----------------------------------|-----------|------|-------|-----------|
|                     | Percent of Customers Interrupted |           |      |       |           |
|                     | Trees                            | Equipment | Ice  | Wind  | All Other |
| Catastrophic Storms | 53.6%                            | 3.7%      | 0.0% | 36.0% | 6.7%      |
| Small Storms        | 43.8%                            | 16.0%     | 0.1% | 27.8% | 12.3%     |
| Non-Storm           | 34.1%                            | 37.6%     | 0.1% | 3.7%  | 24.5%     |
| All Conditions      | 39.3%                            | 27.7%     | 0.1% | 13.8% | 19.1%     |

Reliability Performance and Power Quality Resolution Process  
DTE Electric Report for 2022

**1A. Reliability Performance - 5 Worst Performing SAIFI Circuits - System Basis**

|   | Circuit Name and Number | Substation | Location    | Circuit Miles | Customers Served | SAIFI All Wthr Sys Basis | SAIFI ex MEDs Sys Basis | SAIFI All Wthr Cct Basis | SAIFI ex MEDs Cct Basis | Last Tree Trimming |
|---|-------------------------|------------|-------------|---------------|------------------|--------------------------|-------------------------|--------------------------|-------------------------|--------------------|
| 1 | FISHR8188               | Fisher     | Gibraltar   | 42.5          | 3,161            | 0.0074                   | 0.0074                  | 5.2525                   | 5.2281                  | 2018               |
| 2 | DUBLN8205               | Dublin     | Huron Twp   | 38.8          | 3,440            | 0.0058                   | 0.0039                  | 3.7613                   | 2.5613                  | 2020               |
| 3 | BUNRT8426               | Bunert     | Warren      | 14.7          | 1,593            | 0.0057                   | 0.0056                  | 8.0722                   | 7.8406                  | 2014               |
| 4 | SWANC9408               | Swan Creek | Berlin Twp  | 60.1          | 2,826            | 0.0057                   | 0.0047                  | 4.4812                   | 3.7555                  | 2020               |
| 5 | MACMB8521               | Macomb     | Clinton Twp | 37.5          | 2,990            | 0.0055                   | 0.0044                  | 4.0990                   | 3.3023                  | 2022               |

**1B. Reliability Performance – 5 Worst Performing SAIFI Circuits - Circuit Basis**

|   | Circuit Name and Number | Substation  | Location  | Circuit Miles | Customers Served | SAIFI All Wthr Sys Basis | SAIFI ex MEDs Sys Basis | SAIFI All Wthr Cct Basis | SAIFI ex MEDs Cct Basis | Last Tree Trimming |
|---|-------------------------|-------------|-----------|---------------|------------------|--------------------------|-------------------------|--------------------------|-------------------------|--------------------|
| 1 | WSEND0607               | West End    | Detroit   | 10.8          | 589              | 0.0029                   | 0.0029                  | 11.0696                  | 11.0390                 | 2014               |
| 2 | PURTN1020               | Puritan     | Detroit   | 3.6           | 231              | 0.0009                   | 0.0008                  | 8.5671                   | 7.8442                  | 2018               |
| 3 | BUNRT8426               | Bunert      | Warren    | 14.7          | 1,593            | 0.0057                   | 0.0056                  | 8.0722                   | 7.8406                  | 2014               |
| 4 | MCGRW1321               | Mcgraw      | Detroit   | 2.6           | 239              | 0.0008                   | 0.0008                  | 7.6360                   | 7.6151                  | 2022               |
| 5 | TWEMI1939               | Twelve Mile | Royal Oak | 6.6           | 868              | 0.0027                   | 0.0024                  | 7.0749                   | 6.1959                  | 2021               |

**Corrective Action Plans to Improve SAIFI Performance**

|      | Circuit Name and Number | Corrective Actions                                                                                                                      | Outages and Causes |
|------|-------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|--------------------|
| 1A-1 | FISHR8188               | Customer Excellence work completed in Q4 of 2022. Asset Health work to be completed by 6/1/2023 on sub-transmission line feeding FISHR. | See Appendix 1A    |
| 1A-2 | DUBLN8205               | Customer Excellence work completed in Q4 of 2022.                                                                                       | See Appendix 1A    |
| 1A-3 | BUNRT8426               | Customer Excellence work for sub-transmission lines feeding BUNRT completed in Q4 of 2022.                                              | See Appendix 1A    |
| 1A-4 | SWANC9408               | Customer Excellence work to be completed by 6/1/2023.                                                                                   | See Appendix 1A    |
| 1A-5 | MACMB8521               | Tree Trimming completed in Q4 of 2022; Customer Excellence to be completed by 6/1/2023.                                                 | See Appendix 1A    |
| 1B-1 | WSEND0607               | Customer Excellence work to be completed by Q4 of 2023. Tree Trimming scheduled for Q2 of 2023.                                         | See Appendix 1B    |
| 1B-2 | PURTN1020               | Tree Trimming scheduled for Q2/Q3 of 2023.                                                                                              | See Appendix 1B    |
| 1B-3 | BUNRT8426               | Customer Excellence work for sub-transmission lines feeding BUNRT completed in Q4 of 2022.                                              | See Appendix 1B    |
| 1B-4 | MCGRW1321               | Circuit Hardening and Tree Trimming completed in Q4 of 2022.                                                                            | See Appendix 1B    |
| 1B-5 | TWEMI1939               | Customer Excellence work to be completed by 6/1/2023.                                                                                   | See Appendix 1B    |

Reliability Performance and Power Quality Resolution Process  
DTE Electric Report for 2022

**2A. Reliability Performance - 5 Worst Performing SAIDI Circuits - System Basis**

|   | Circuit Name and Number | Substation | Location         | Circuit Miles | Customers Served | SAIDI All Wthr Sys Basis | SAIDI ex MEDs Sys Basis | SAIDI All Wthr Cct Basis | SAIDI ex MEDs Cct Basis | Last Tree Trimming |
|---|-------------------------|------------|------------------|---------------|------------------|--------------------------|-------------------------|--------------------------|-------------------------|--------------------|
| 1 | CONRD8130               | Conrad     | Howell Twp       | 153.3         | 2,688            | 4.58                     | 0.35                    | 3814.59                  | 288.62                  | 2021               |
| 2 | SLOAN8524               | Sloan      | Sterling Heights | 23.4          | 2,560            | 3.98                     | 0.11                    | 3487.61                  | 93.70                   | 2015               |
| 3 | PROUD9475               | Proud      | Milford Twp      | 59.9          | 3,259            | 3.79                     | 0.31                    | 2608.59                  | 210.82                  | 2014               |
| 4 | AKRON9000               | Akron      | Novi             | 38.3          | 3,442            | 3.41                     | 0.11                    | 2220.86                  | 69.41                   | 2014               |
| 5 | LOMRD8516               | Lombard    | Warren           | 16.9          | 2,124            | 3.30                     | 0.29                    | 3480.14                  | 307.37                  | 2014               |

**2B. Reliability Performance - 5 Worst Performing SAIDI Circuits - Circuit Basis**

|   | Circuit Name and Number | Substation | Location   | Circuit Miles | Customers Served | SAIDI All Wthr Sys Basis | SAIDI ex MEDs Sys Basis | SAIDI All Wthr Cct Basis | SAIDI ex MEDs Cct Basis | Last Tree Trimming |
|---|-------------------------|------------|------------|---------------|------------------|--------------------------|-------------------------|--------------------------|-------------------------|--------------------|
| 1 | LYNCH2260               | Lynch Road | Detroit    | 10.5          | 201              | 0.57                     | 0.01                    | 6366.71                  | 122.71                  | 2019               |
| 2 | EVRGN2166               | Evergreen  | Detroit    | 6.4           | 985              | 2.47                     | 0.08                    | 5626.33                  | 185.59                  | 2022               |
| 3 | MEYRS1691               | Meyers     | Detroit    | 7.4           | 766              | 1.85                     | 0.01                    | 5397.07                  | 25.64                   | 2022               |
| 4 | EVRGN1766               | Evergreen  | Detroit    | 5.0           | 656              | 1.54                     | 0.21                    | 5244.74                  | 713.23                  | 2022               |
| 5 | MADRD9933               | Madrid     | Marion Twp | 67.6          | 837              | 1.96                     | 0.14                    | 5235.02                  | 371.39                  | 2020               |

**Corrective Action Plans to Improve SAIDI Performance**

|      | Circuit Name and Number | Corrective Actions                                                                                                                                                                                                    | Outages and Causes |
|------|-------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|
| 2A-1 | CONRD8130               | Pole-top maintenance ongoing as of March 2023, expected to be completed before end of year. 4 of the top 5 longest events make up 88% of the minutes, occurred on major event days (storms).                          | See Appendix 2A    |
| 2A-2 | SLOAN8524               | 97% of customer minutes occurred during one single event, which was a major event day (storm). Pole-top maintenance ongoing as of March 2023, expected to be completed before end of year.                            | See Appendix 2A    |
| 2A-3 | PROUD9475               | 91% of customer minutes occurred during one single event in 2022, which was a major event day (storm). URD cable replacement (approximately 2,000 feet) in select locations, expected to be completed by end of year. | See Appendix 2A    |
| 2A-4 | AKRON9000               | 97% of customer minutes were from the August CAT storm. Corrective actions were taken at that time.                                                                                                                   | See Appendix 2A    |
| 2A-5 | LOMRD8516               | 91% of customer minutes occurred during a single event during the August CAT storm. Corrective actions were taken at that time.                                                                                       | See Appendix 2A    |
| 2B-1 | LYNCH2260               | 94% of customer minutes were from the August CAT storm. Corrective actions were taken at the time.                                                                                                                    | See Appendix 2B    |
| 2B-2 | EVRGN2166               | Tree Trimming completed in Q4 of 2022; Circuit Hardening scheduled for 2023.                                                                                                                                          | See Appendix 2B    |
| 2B-3 | MEYRS1691               | Tree Trimming completed in Q4 of 2022; Pole top maintenance scheduled for 2023.                                                                                                                                       | See Appendix 2B    |
| 2B-4 | EVRGN1766               | Tree Trimming completed in Q4 of 2022; Circuit Hardening scheduled for 2023.                                                                                                                                          | See Appendix 2B    |
| 2B-5 | MADRD9933               | 90% of customer minutes occurred during major event days (storms). Pole-top maintenance completed late 2022; sectionalizing upgrades taking place now, expected to complete June 2023.                                | See Appendix 2B    |

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**Reliability Performance – Customers Experiencing Multiple Interruptions (CEMI)**

Per IEEE Definition, CEMI n represents the number of customers experiencing n or more interruptions. Hence, in the table below, each discrete CEMI level is a subset of the CEMI levels above it.

| <b>CEMI N</b> | <b># Customers</b> |
|---------------|--------------------|
| CEMI 0        | 2,240,565          |
| CEMI 1        | 1,413,826          |
| CEMI 2        | 730,375            |
| CEMI 3        | 351,325            |
| CEMI 4        | 163,417            |
| CEMI 5        | 73,297             |
| CEMI 6        | 33,773             |
| CEMI 7        | 16,262             |
| CEMI 8        | 6,990              |
| CEMI 9        | 3,225              |
| CEMI 10+      | 1,583              |

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**Reliability Performance – Customers Experiencing Long Interruption Duration (CELID)**

The CELID customer count is based on the Single Interruption Duration (rather than the Total Interruption Duration) defined in IEEE Standard 1366-2012, Section 3.2.8, Equation 15; i.e. it represents each occasion a customer was interrupted based on the CELID duration, not the total time during the year that each customer was interrupted.

| <b>CELID - Single Interruption Duration</b>    | <b># Customers</b> |
|------------------------------------------------|--------------------|
| CELID 8 hours - MPSC Normal Conditions         | 174,178            |
| CELID 16 hours - MPSC Normal Conditions        | 81,905             |
| CELID 60 hours - MPSC Catastrophic Conditions  | 76,618             |
| CELID 120 hours - MPSC Catastrophic Conditions | 388                |

Per MPSC Case U-12270, catastrophic conditions are defined by either of the following:

- (a) severe weather conditions that result in service interruptions for 10% or more of a utility's customers
- (b) events of sufficient magnitude that result in the issuance of an official state of emergency declaration by the local, state, or federal government



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**Power Quality Inquiry Process**

DTE Electric (DTE) has a proven effective process in place that enables its large industrial and commercial customers typically served off the subtransmission or transmission system to obtain resolution of power quality issues. The customers contact their assigned account representative who in turn starts the process of helping the customer by engaging the appropriate engineer in Distribution Operations. DTE and ITC Transmission (ITCT) have a very successful process concerning the transmission system events.

The response to the customer normally includes the following steps:

- (1) Obtain pertinent information about what is troubling the customer (old or new equipment, one device or many)
- (2) Gather the dates and times from the customer to correlate with EMS Alarm Logger events (cap switching, line trips)
- (3) Correlate the customer's experiences with the power quality meters at his service point or with power quality meters in the area
- (4) Meet with the customer about the correlation of system and customer events.

Based on the correlation of DTE and customer events, the following outcomes or additional steps are possible:

- (1) Special power quality monitoring (DTE or customer) could be installed to determine customer equipment sensitivity and source of problem.
- (2) Customer conducts site survey to determine if his operating voltage is optimal
- (3) Trouble with minor sags from DTE system (sensitive equipment) - customer's responsibility to make compatible.
- (4) Internal system trouble - customer's responsibility to make equipment compatible
- (5) ITCT/DTE will seek resolution of problems caused on the ITCT/DTE systems where the customer equipment wouldn't be expected to have ride-through to significant voltage sags. The rate of occurrence, system exposure and service method determine if remedies are commercially feasible.

Reliability Performance and Power Quality Resolution Process  
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**Power Quality Monitoring**

DTE has an array of power quality meters across its system at key industrial, subtransmission, and distribution buses that have proven to be very effective. New meters are installed at new or upgraded industrial substations and on subtransmission buses.

The power quality meters at the industrial locations allow DTE to correlate the recorded voltage sags with system events from the SCADA-EMS system. This system provides DTE with information unique to the customer and a tool to track the performance of the system. The system performance data is used to prioritize capital improvements and system maintenance.

The power quality meters on the subtransmission and distribution buses provide system performance data. This information will reduce the time and cost to find causes of voltage sags and facilitate repair the system when necessary.

Also, voltage sags on the DTE system can be correlated with faults on the ITCT system. The DTE power quality data is shared with ITCT for the benefit of resolving customer power quality issues.

Reliability Performance and Power Quality Resolution Process  
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**2022 Power Quality Inquiries Summary**

The data below indicates the total number of power quality events correlated by DTE – Distribution Operations in 2022. Each power quality issue is categorized by service methods, power quality events, source of events.

| Inquiries |       |                            | Power Quality Event <sup>1</sup> |              | PQ Event Source  |                   |                       | Detail <sup>6</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|-----------|-------|----------------------------|----------------------------------|--------------|------------------|-------------------|-----------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Month     | Total | Loc. Impacted <sup>2</sup> | Voltage Sag                      | Interruption | DTE <sup>3</sup> | ITCT <sup>4</sup> | Customer <sup>5</sup> | Inquiry Numbers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Jan       | 21    | 45                         | 44                               | 1            | 41               | 1                 | 3                     | 10277, 10281, 10303, 10249, 10270, 10259, 10271, 10269, 10278, 10315, 10335, 10304, 10248, 10320, 10331, 10301, 10333, 10288, 10239, 10332, 10282                                                                                                                                                                                                                                                                                                                                                 |
| Feb       | 31    | 85                         | 78                               | 7            | 33               | 190               | 35                    | 10249, 10277, 10288, 10267, 10319, 10308, 10272, 10328, 10296, 10252, 10269, 10313, 10327, 10259, 10236, 10310, 10286, 10278, 10238, 10324, 10247, 10331, 10266, 10329, 10326, 10330, 10315, 10325, 10257, 10312, 10244                                                                                                                                                                                                                                                                           |
| Mar       | 64    | 163                        | 151                              | 12           | 151              | 9                 | 3                     | 10329, 10326, 10249, 10288, 10245, 10262, 10246, 10272, 10277, 10304, 10248, 10303, 10280, 10259, 10319, 10283, 10242, 10320, 10256, 10278, 10300, 10287, 10238, 10299, 10261, 10274, 10318, 10236, 10279, 10306, 10240, 10241, 10291, 10336, 10331, 10254, 10332, 10334, 10284, 10281, 10264, 10292, 10243, 10269, 10250, 10302, 10293, 10338, 10301, 10315, 10333, 10267, 10271, 10265, 10275, 10237, 10255, 10282, 10260, 10311, 10298, 10310, 10322, 10257                                    |
| Apr       | 69    | 132                        | 122                              | 10           | 121              | 0                 | 11                    | 10266, 10264, 10331, 10268, 10326, 10329, 10246, 10262, 10257, 10274, 10306, 10318, 10296, 10270, 10243, 10321, 10279, 10260, 10294, 10269, 10250, 10312, 10307, 10251, 10276, 10285, 10290, 10330, 10241, 10239, 10271, 10304, 10334, 10265, 10298, 10256, 10332, 10253, 10337, 10258, 10263, 10289, 10316, 10308, 10328, 10280, 10254, 10240, 10247, 10252, 10286, 10305, 10313, 10317, 10324, 10327, 10336, 10325, 10244, 10236, 10261, 10291, 10309, 10237, 10302, 10314, 10275, 10297, 10301 |

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|              |            |             |            |           |            |            |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|--------------|------------|-------------|------------|-----------|------------|------------|-----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| May          | 28         | 62          | 57         | 5         | 58         | 1          | 3         | 10238, 10320, 10260, 10315, 10277, 10262, 10272, 10278, 10319, 10257, 10289, 10335, 10249, 10251, 10280, 10322, 10311, 10271, 10334, 10303, 10270, 10294, 10269, 10267, 10323, 10331, 10250, 10246                                                                                                                                                                                                                                                                                                       |
| June         | 58         | 151         | 147        | 6         | 137        | 14         | 0         | 10323, 10331, 10326, 10274, 10306, 10241, 10318, 10278, 10277, 10320, 10250, 10319, 10246, 10267, 10303, 10249, 10272, 10312, 10307, 10257, 10254, 10328, 10327, 10305, 10259, 10252, 10296, 10313, 10285, 10308, 10240, 10317, 10286, 10324, 10336, 10238, 10247, 10290, 10251, 10288, 10325, 10256, 10276, 10330, 10239, 10281, 10242, 10315, 10333, 10271, 10269, 10304, 10248                                                                                                                        |
| July         | 58         | 153         | 146        | 7         | 119        | 34         | 0         | 10322, 10311, 10271, 10269, 10278, 10277, 10331, 10262, 10246, 10256, 10318, 10332, 10264, 10298, 10265, 10319, 10321, 10272, 10289, 10245, 10263, 10335, 10238, 10258, 10316, 10290, 10251, 10249, 10330, 10337, 10253, 10328, 10308, 10320, 10280, 10259, 10274, 10306, 10244, 10312, 10242, 10257, 10315, 10270, 10250, 10266, 10323, 10326, 10268, 10329, 10288, 10241, 10317, 10285, 10248, 10304, 10334, 10333                                                                                     |
| Aug          | 70         | 92          | 86         | 6         | 87         | 5          | 0         | 10277, 10303, 10331, 10259, 10256, 10319, 10238, 10272, 10276, 10337, 10248, 10260, 10274, 10280, 10278, 10310, 10244, 10306, 10318, 10327, 10249, 10243, 10321, 10288, 10251, 10290, 10334, 10246, 10262, 10241, 10317, 10236, 10240, 10247, 10261, 10285, 10287, 10291, 10305, 10309, 10324, 10336, 10269, 10268, 10326, 10329, 10323, 10300, 10307, 10237, 10302, 10266, 10281, 10311, 10322, 10245, 10314, 10320, 10270, 10315, 10239, 10267, 10275, 10297, 10298, 10301, 10304, 10333, 10250, 10242 |
| Sept         | 53         | 88          | 79         | 9         | 79         | 9          | 0         | 10243, 10244, 10321, 10323, 10326, 10331, 10319, 10274, 10277, 10306, 10318, 10300, 10238, 10272, 10307, 10249, 10288, 10237, 10260, 10302, 10334, 10266, 10268, 10329, 10281, 10280, 10278, 10248, 10311, 10322, 10245, 10314, 10256, 10320, 10270, 10315, 10236, 10239, 10251, 10267, 10269, 10275, 10297, 10298, 10301, 10303, 10304, 10333, 10259, 10285, 10317, 10250, 10242                                                                                                                        |
| *Oct         | 12         | 35          | 31         | 4         | 20         | 15         | 0         | 10245, 10319, 10314, 10326, 10238, 10256, 10277, 10331, 10318, 10315, 10236, 10237                                                                                                                                                                                                                                                                                                                                                                                                                       |
| *Nov         | 0          | 0           | 0          | 0         | 0          | 0          | 0         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| *Dec         | 1          | 1           | 0          | 1         | 1          | 0          | 0         | 10318                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>Total</b> | <b>460</b> | <b>1007</b> | <b>941</b> | <b>68</b> | <b>847</b> | <b>107</b> | <b>55</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |

Reliability Performance and Power Quality Resolution Process  
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- 
- 1 Voltages and durations (IEEE Std 1159 Table 2 – Categories & Typical Characteristics of Power System Phenomena)
  - 2 Number of unique customer locations impacted per system event ID
  - 3 Equipment owned by DTE (120, 40, 24, 13.2 and 4.8 kV)
  - 4 Equipment owned by ITCT (345, 230 and 120 kV)
  - 5 Equipment owned by the customer or other power systems not owned by DTE or ITCT
  - 6 Inquiry numbers – event detail provided in the table below
- \* Insufficient data for months of October-December. Due to metering issues, some events may not have been captured.
-

## Reliability Performance and Power Quality Resolution Process DTE Electric Report for 2022

The number of locations impacted and identified by power quality monitors, system monitors, and customer inquiries was 1007 during 2022, which was less than the 1177 total in 2021. By the end of 2022, the ION 8650 meter installation project had installed 375 (2019-2022) new power quality meters at Industrial Substation customer sites throughout the system.

The follow-up investigations indicate that most of the power quality events were due to either voltage sags (93.4%) or interruptions (6.55%) and correlated with trouble occurring on the DTE (84.01%) and ITCT (15.98%) systems. Of the events on the DTE and ITCT system 25.2% were attributed to adverse weather.

Line clearance, system modifications such as operating practice changes, equipment replacement or maintenance, and adding animal guards/protection are all typical actions taken to reduce the occurrences of the events.

The following table lists information about each inquiry:

| Inquiry | Date - Time   | System Event                               | PQ Event     | Comments <sup>1</sup> |
|---------|---------------|--------------------------------------------|--------------|-----------------------|
| 10236   | 2/17/22 22:40 | River Rouge - Navarre                      | Interruption | weather               |
| 10236   | 2/19/22 0:42  | Limited Data to identify affected elements | Voltage Sag  | customer              |
| 10236   | 3/31/22 8:05  | Newburgh - Peru                            | Voltage Sag  | weather               |
| 10236   | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather               |
| 10236   | 8/30/22 16:59 | Monroe - Lallendorf                        | Voltage Sag  | line equip            |
| 10236   | 4/1/22 09:14  | Tulsa 1                                    | Voltage Sag  | unknown               |
| 10237   | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather               |
| 10237   | 9/19/22 5:56  | Sterling Trunk 2719                        | Voltage Sag  | unknown               |
| 10237   | 9/25/22 09:37 | STPS 21 TRF1                               | Interruption | station equip         |
| 10237   | 9/30/22 17:33 | Crawford DC 8301                           | Interruption | unknown               |
| 10237   | 4/1/22 09:14  | STPS 21                                    | Voltage Sag  | unknown               |
| 10238   | 2/17/22 22:39 | River Rouge - Navarre                      | Voltage Sag  | weather               |
| 10238   | 2/17/22 22:40 | River Rouge - Navarre                      | Voltage Sag  | weather               |
| 10238   | 3/30/22 6:07  | Coventry - Wixom                           | Voltage Sag  | weather               |
| 10238   | 3/31/22 8:05  | Newburgh - Peru                            | Voltage Sag  | weather               |
| 10238   | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather               |
| 10238   | 4/26/22 11:07 | Limited Data to identify affected elements | Voltage Sag  | customer              |
| 10238   | 5/10/22 13:55 | Limited Data to identify affected elements | Voltage Sag  | unknown               |
| 10238   | 5/10/22 14:35 | Limited Data to identify affected elements | Voltage Sag  | unknown               |
| 10238   | 5/21/22 9:25  | Limited Data to identify affected elements | Voltage Sag  | unknown               |
| 10238   | 5/21/22 10:57 | Limited Data to identify affected elements | Voltage Sag  | unknown               |

<sup>1</sup> When "unknown" is indicated, the issue was resolved, but no cause could be found at the time of the investigation. Possible causes could be interference (animal, public, material - including trees), weather (lightning, wind, ice), or customer-related issues (where DTE does not have access to customer's system/data to determine cause).

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|       |                |                                            |             |               |
|-------|----------------|--------------------------------------------|-------------|---------------|
| 10238 | 6/3/22 20:06   | Pontiac-Placid                             | Voltage Sag | station equip |
| 10238 | 6/3/22 20:22   | Pontiac-Placid                             | Voltage Sag | station equip |
| 10238 | 6/16/22 9:21   | Brownstown - Berlin                        | Voltage Sag | weather       |
| 10238 | 6/24/22 23:38  | Limited Data to identify affected elements | Voltage Sag | Interference  |
| 10238 | 7/15/22 19:21  | River Rouge - Warren 2                     | Voltage Sag | Interference  |
| 10238 | 7/31/22 8:25   | Monroe - Wayne                             | Voltage Sag | line equip    |
| 10238 | 8/20/22 16:51  | Milan - Monroe Power Plant                 | Voltage Sag | weather       |
| 10238 | 8/30/22 16:59  | Monroe - Lallendorf                        | Voltage Sag | line equip    |
| 10238 | 9/6/22 11:22   | Keith - Waterman                           | Voltage Sag | unknown       |
| 10238 | 9/12/22 6:06   | Brownstown - Navarre 2                     | Voltage Sag | unknown       |
| 10238 | 9/12/22 6:08   | Brownstown - Navarre 2                     | Voltage Sag | unknown       |
| 10238 | 9/19/22 21:13  | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10238 | 9/21/22 8:12   | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10238 | 10/11/22 14:04 | Arrowhead                                  | Voltage Sag | unknown       |
| 10238 | 10/11/22 15:53 | Arrowhead                                  | Voltage Sag | unknown       |
| 10238 | 10/11/22 14:04 | Arrowhead                                  | Voltage Sag | unknown       |
| 10238 | 10/11/22 15:53 | Arrowhead                                  | Voltage Sag | unknown       |
| 10238 | 10/4/22 21:47  | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10238 | 10/6/22 16:16  | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10238 | 10/6/22 17:33  | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10238 | 9/22/22 14:38  | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10238 | 9/25/22 04:08  | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10238 | 4/1/22 09:14   | DB042 2                                    | Voltage Sag | unknown       |
| 10239 | 1/7/22 12:17   | Wheeler Transformer 2                      | Voltage Sag | station equip |
| 10239 | 6/3/22 20:05   | Pontiac-Placid                             | Voltage Sag | station equip |
| 10239 | 6/3/22 20:22   | Pontiac-Placid                             | Voltage Sag | station equip |
| 10239 | 4/1/22 9:14    | Eclipse 1                                  | Voltage Sag | unknown       |
| 10240 | 3/31/22 8:05   | Newburgh - Peru                            | Voltage Sag | weather       |
| 10240 | 6/16/22 9:21   | Brownstown - Berlin                        | Voltage Sag | weather       |
| 10240 | 8/30/22 16:59  | Monroe - Lallendorf                        | Voltage Sag | line equip    |
| 10241 | 3/31/22 8:05   | Newburgh - Peru                            | Voltage Sag | weather       |
| 10241 | 6/1/22 12:27   | Newburgh Trunk 2002                        | Voltage Sag | weather       |
| 10241 | 8/30/22 16:59  | Monroe - Lallendorf                        | Voltage Sag | line equip    |
| 10241 | 7/6/22 14:39   | Dayton - Romulus                           | Voltage Sag | unknown       |
| 10242 | 3/26/22 6:05   | Limited Data to identify affected elements | Voltage Sag | station equip |
| 10242 | 3/31/22 8:27   | Belle River Bus 302                        | Voltage Sag | weather       |
| 10242 | 4/13/22 14:11  | Limited Data to identify affected elements | Voltage Sag | customer      |
| 10242 | 6/3/22 20:05   | Pontiac-Placid                             | Voltage Sag | station equip |

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|       |               |                                            |             |               |
|-------|---------------|--------------------------------------------|-------------|---------------|
| 10242 | 6/3/22 20:22  | Pontiac-Placid                             | Voltage Sag | station equip |
| 10242 | 7/25/22 1:23  | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10242 | 8/7/22 15:58  | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10242 | 9/28/22 14:21 | Carter Transformer 1                       | Voltage Sag | unknown       |
| 10243 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag | weather       |
| 10243 | 4/24/22 20:55 | Colfax - Tie 6310                          | Voltage Sag | unknown       |
| 10243 | 8/11/22 0:54  | Genoa Tie 5843                             | Voltage Sag | interference  |
| 10243 | 9/8/22 9:19   | Genoa Trunk 5855                           | Voltage Sag | unknown       |
| 10243 | 10/6/22 17:50 | Genoa Trunk 5838                           | Voltage Sag | unknown       |
| 10243 | 4/1/22 09:14  | Spain 1                                    | Voltage Sag | unknown       |
| 10244 | 2/26/22 12:52 | Colfax-Genoa 5823                          | Voltage Sag | unknown       |
| 10244 | 7/24/22 4:36  | Colfax - Tie 5823                          | Voltage Sag | unknown       |
| 10244 | 8/8/22 8:33   | Colfax - Genoa Tie 5823                    | Voltage Sag | unknown       |
| 10244 | 8/9/22 19:51  | Colfax Trunk 6304                          | Voltage Sag | line equip    |
| 10244 | 8/11/22 0:53  | Genoa Tie 5843                             | Voltage Sag | interference  |
| 10244 | 9/8/22 9:19   | Genoa Trunk 5855                           | Voltage Sag | unknown       |
| 10244 | 9/19/22 4:49  | Colfax Trunk 6304                          | Voltage Sag | unknown       |
| 10244 | 10/6/22 17:49 | Genoa Trunk 5838                           | Voltage Sag | unknown       |
| 10245 | 3/1/22 19:58  | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10245 | 3/2/22 0:45   | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10245 | 3/6/22 9:33   | Hines-Plymouth 2901                        | Voltage Sag | weather       |
| 10245 | 4/17/22 16:17 | Hines Trunk 2931                           | Voltage Sag | line equip    |
| 10245 | 4/29/22 14:48 | Yost - Trunk 5404                          | Voltage Sag | unknown       |
| 10245 | 7/15/22 19:21 | River Rouge - Warren 2                     | Voltage Sag | Interference  |
| 10245 | 7/24/22 22:18 | Evergreen Trunk 2247                       | Voltage Sag | unknown       |
| 10245 | 7/25/22 12:24 | Evergreen Trunk 2247                       | Voltage Sag | unknown       |
| 10245 | 7/31/22 8:25  | Monroe - Wayne                             | Voltage Sag | line equip    |
| 10245 | 10/8/22 11:32 | Hines Bus 103                              | Voltage Sag | unknown       |
| 10246 | 3/6/22 12:54  | Northwest Trunk 2443-44                    | Voltage Sag | weather       |
| 10246 | 3/6/22 13:24  | Northwest Trunk 2443-44                    | Voltage Sag | weather       |
| 10246 | 3/7/22 22:02  | Northwest Trunk 2427-28                    | Voltage Sag | line equip    |
| 10246 | 3/10/22 15:39 | Northwest Trunk 2411                       | Voltage Sag | interference  |
| 10246 | 4/14/22 18:53 | Northwest Trunk 2443                       | Voltage Sag | weather       |
| 10246 | 4/15/22 21:20 | Northwest Trunk 2411                       | Voltage Sag | weather       |
| 10246 | 5/8/22 7:40   | Northwest Bus 2                            | Voltage Sag | station equip |
| 10246 | 6/12/22 6:32  | Northwest Trunk 2466                       | Voltage Sag | unknown       |
| 10246 | 6/24/22 7:33  | Northwest Trunk 2439                       | Voltage Sag | conductor     |
| 10246 | 7/10/22 18:33 | Northwest Trunk 2466                       | Voltage Sag | unknown       |
| 10246 | 8/30/22 7:24  | Northwest Trunk 2439                       | Voltage Sag | weather       |
| 10247 | 2/17/22 22:40 | River Rouge - Navarre                      | Voltage Sag | weather       |
| 10247 | 6/16/22 9:21  | Brownstown - Berlin                        | Voltage Sag | weather       |
| 10247 | 8/30/22 16:59 | Monroe - Lallendorf                        | Voltage Sag | line equip    |
| 10248 | 1/31/22 8:31  | Macomb Trunk 2305                          | Voltage Sag | unknown       |



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|       |               |                                            |              |               |
|-------|---------------|--------------------------------------------|--------------|---------------|
| 10248 | 3/14/22 11:39 | Macomb Trunk 2305                          | Voltage Sag  | unknown       |
| 10248 | 3/31/22 8:28  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10248 | 3/31/22 12:58 | Boyne - Trunk 7913                         | Voltage Sag  | weather       |
| 10248 | 6/7/22 6:59   | Benson Transformer 1                       | Voltage Sag  | unknown       |
| 10248 | 7/8/22 0:52   | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10248 | 7/8/22 1:08   | Jewell-Puttygut                            | Voltage Sag  | unknown       |
| 10248 | 8/20/22 18:48 | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10248 | 9/3/22 14:18  | Chesterfield Transformer 1                 | Voltage Sag  | station equip |
| 10248 | 10/5/22 11:48 | Jewell - Stephens                          | Voltage Sag  | unknown       |
| 10248 | 9/25/22 15:31 | Macomb Trunk 2301                          | Interruption | unknown       |
| 10248 | 4/1/22 09:15  | Butler 2                                   | Voltage Sag  | unknown       |
| 10249 | 1/7/22 12:17  | Wheeler Transformer 2                      | Voltage Sag  | station equip |
| 10249 | 1/7/22 12:17  | Wheeler Transformer 2                      | Voltage Sag  | station equip |
| 10249 | 1/11/22 8:17  | Spokane-Oxford 6931                        | Voltage Sag  | unknown       |
| 10249 | 2/11/22 10:30 | Phoenix Trunk 7150-51                      | Voltage Sag  | unknown       |
| 10249 | 2/11/22 20:08 | Troy Trunk 3511-12                         | Voltage Sag  | conductor     |
| 10249 | 3/1/22 13:53  | Troy Trunk 3540                            | Voltage Sag  | conductor     |
| 10249 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10249 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10249 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10249 | 4/14/22 16:17 | Savage DC 8146                             | Voltage Sag  | conductor     |
| 10249 | 4/14/22 19:18 | Savage DC 8146                             | Voltage Sag  | weather       |
| 10249 | 4/18/22 16:49 | Oxford - Spokane Tie 6931                  | Voltage Sag  | unknown       |
| 10249 | 5/17/22 9:45  | Evergreen Transformer 3                    | Voltage Sag  | station equip |
| 10249 | 5/21/22 10:02 | Troy Trunk 3546                            | Voltage Sag  | weather       |
| 10249 | 5/24/22 10:43 | Spokane Trunk 6919                         | Voltage Sag  | interference  |
| 10249 | 5/24/22 12:03 | Spokane Trunk 6919                         | Voltage Sag  | interference  |
| 10249 | 6/3/22 20:06  | Pontiac-Placid                             | Voltage Sag  | station equip |
| 10249 | 6/3/22 20:23  | Pontiac-Placid                             | Voltage Sag  | station equip |
| 10249 | 6/14/22 8:49  | Spokane Trunk 6919                         | Voltage Sag  | interference  |
| 10249 | 6/16/22 17:33 | Troy Trunk 3546                            | Voltage Sag  | conductor     |
| 10249 | 6/29/22 23:49 | Troy Trunk 3508-09                         | Voltage Sag  | conductor     |
| 10249 | 7/16/22 9:01  | Southfield Trunk 7122                      | Voltage Sag  | unknown       |
| 10249 | 7/17/22 14:56 | Gary                                       | Voltage Sag  | unknown       |
| 10249 | 7/28/22 19:18 | Troy Trunk 3518                            | Voltage Sag  | unknown       |
| 10249 | 8/10/22 8:31  | Spokane Trunk 6941                         | Voltage Sag  | unknown       |
| 10249 | 8/14/22 17:31 | Troy Trunk 3508                            | Voltage Sag  | conductor     |
| 10249 | 9/19/22 5:46  | Troy Trunk 3557                            | Voltage Sag  | unknown       |
| 10249 | 9/19/22 5:56  | Sterling Trunk 2719                        | Voltage Sag  | unknown       |
| 10249 | 9/20/22 9:57  | Southfield Trunk 7122                      | Voltage Sag  | unknown       |
| 10249 | 4/1/22 09:14  | Odyssey 1                                  | Voltage Sag  | unknown       |
| 10250 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10250 | 4/4/22 22:13  | Bunce Creek                                | Voltage Sag  | unknown       |
| 10250 | 5/27/22 16:27 | Imlay City -Yale 3220                      | Voltage Sag  | unknown       |
| 10250 | 6/11/22 10:03 | Bernard - Imlay City - Yale 3220           | Voltage Sag  | unknown       |

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|-------|----------------|--------------------------------------------|--------------|---------------|
| 10250 | 7/27/22 15:17  | Imlay City -Yale 3220                      | Voltage Sag  | unknown       |
| 10250 | 10/6/22 20:31  | Bernard TIE 3220                           | Voltage Sag  | unknown       |
| 10251 | 5/17/22 10:36  | Hager - Sunset                             | Voltage Sag  | intentional   |
| 10251 | 6/3/22 20:07   | Pontiac-Placid                             | Voltage Sag  | station equip |
| 10251 | 6/3/22 20:24   | Pontiac-Placid                             | Voltage Sag  | station equip |
| 10251 | 6/16/22 9:22   | Brownstown - Berlin                        | Voltage Sag  | weather       |
| 10251 | 6/24/22 23:39  | Limited Data to identify affected elements | Voltage Sag  | Interference  |
| 10251 | 7/8/22 1:09    | Jewell-Puttygut                            | Voltage Sag  | unknown       |
| 10251 | 7/15/22 19:22  | River Rouge - Warren 2                     | Voltage Sag  | Interference  |
| 10251 | 7/31/22 8:26   | Monroe - Wayne                             | Voltage Sag  | line equip    |
| 10251 | 8/15/22 10:25  | Akron-Wixom                                | Voltage Sag  | intentional   |
| 10251 | 4/1/22 09:15   | Magneto 2                                  | Voltage Sag  | unknown       |
| 10252 | 2/17/22 22:39  | River Rouge - Navarre                      | Voltage Sag  | weather       |
| 10252 | 6/16/22 9:20   | Brownstown - Berlin                        | Voltage Sag  | weather       |
| 10253 | 7/16/22 17:50  | Custer - Monroe Power Plant                | Voltage Sag  | unknown       |
| 10254 | 3/31/22 8:27   | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10254 | 6/16/22 5:08   | Bad Axe - Pigeon Tie 3416                  | Voltage Sag  | weather       |
| 10255 | 3/31/22 8:27   | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10256 | 3/28/22 12:54  | Springwells Pumping Transformer 1          | Voltage Sag  | customer      |
| 10256 | 3/31/22 8:27   | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10256 | 6/20/22 12:53  | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10256 | 7/10/22 18:47  | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10256 | 7/13/22 10:41  | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10256 | 8/8/22 14:25   | Lee - Sandusky Tie 4105                    | Interruption | unknown       |
| 10256 | 8/19/22 8:03   | Limited Data to identify affected elements | Interruption | unknown       |
| 10256 | 10/11/22 17:19 | Arrowhead                                  | Voltage Sag  | unknown       |
| 10256 | 10/11/22 17:19 | Arrowhead                                  | Voltage Sag  | unknown       |
| 10256 | 4/1/22 09:14   | Tulsa 2                                    | Voltage Sag  | unknown       |
| 10257 | 2/2/22 10:28   | Limited Data to identify affected elements | Voltage Sag  | customer      |
| 10257 | 2/2/22 11:20   | Limited Data to identify affected elements | Voltage Sag  | customer      |
| 10257 | 2/2/22 14:52   | Limited Data to identify affected elements | Voltage Sag  | customer      |
| 10257 | 2/3/22 13:39   | Limited Data to identify affected elements | Voltage Sag  | customer      |
| 10257 | 2/3/22 14:43   | Limited Data to identify affected elements | Voltage Sag  | customer      |
| 10257 | 3/6/22 8:24    | Derby-Tuscola 9123                         | Voltage Sag  | weather       |
| 10257 | 4/15/22 12:47  | Derby - Hunters Creek 9111                 | Voltage Sag  | weather       |
| 10257 | 5/14/22 23:16  | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10257 | 6/16/22 4:31   | Derby - Tuscola Tie 9123                   | Voltage Sag  | weather       |

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|       |               |                                            |              |               |
|-------|---------------|--------------------------------------------|--------------|---------------|
| 10257 | 7/26/22 5:39  | Derby Tie 9107                             | Voltage Sag  | unknown       |
| 10258 | 7/15/22 19:21 | River Rouge - Warren 2                     | Voltage Sag  | Interference  |
| 10259 | 1/2/22 14:29  | Limited Data to identify affected elements | Voltage Sag  | customer      |
| 10259 | 2/3/22 6:22   | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10259 | 2/17/22 22:39 | River Rouge - Navarre                      | Voltage Sag  | weather       |
| 10259 | 2/17/22 22:39 | River Rouge - Navarre                      | Voltage Sag  | weather       |
| 10259 | 3/25/22 2:52  | Limited Data to identify affected elements | Interruption | unknown       |
| 10259 | 3/25/22 3:13  | Limited Data to identify affected elements | Interruption | unknown       |
| 10259 | 3/31/22 8:04  | Newburgh - Peru                            | Voltage Sag  | weather       |
| 10259 | 3/31/22 8:05  | Newburgh - Peru                            | Voltage Sag  | weather       |
| 10259 | 3/31/22 8:05  | Newburgh - Peru                            | Voltage Sag  | weather       |
| 10259 | 4/2/22 23:39  | Romulus-Trenton                            | Voltage Sag  | unknown       |
| 10259 | 4/2/22 23:39  | Romulus-Trenton                            | Voltage Sag  | unknown       |
| 10259 | 6/16/22 9:20  | Brownstown - Berlin                        | Voltage Sag  | weather       |
| 10259 | 6/16/22 9:20  | Brownstown - Berlin                        | Voltage Sag  | weather       |
| 10259 | 7/20/22 14:57 | Fleming - Romulus Tie 7702                 | Voltage Sag  | weather       |
| 10259 | 7/20/22 14:57 | Fleming - Romulus Tie 7702                 | Voltage Sag  | weather       |
| 10259 | 8/17/22 22:56 | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10259 | 8/30/22 16:59 | Monroe - Lallendorf                        | Voltage Sag  | line equip    |
| 10259 | 8/30/22 16:59 | Monroe - Lallendorf                        | Voltage Sag  | line equip    |
| 10259 | 8/30/22 16:59 | Monroe - Lallendorf                        | Voltage Sag  | line equip    |
| 10259 | 10/2/22 13:38 | Wick DC 9352                               | Voltage Sag  | unknown       |
| 10259 | 7/6/22 14:40  | Dayton - Romulus                           | Voltage Sag  | unknown       |
| 10259 | 7/6/22 14:40  | Dayton - Romulus                           | Voltage Sag  | unknown       |
| 10259 | 7/6/22 15:27  | Dayton - Romulus                           | Voltage Sag  | unknown       |
| 10260 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10260 | 5/11/22 17:08 | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10260 | 8/20/22 18:41 | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10260 | 9/19/22 5:56  | Sterling Trunk 2719                        | Voltage Sag  | unknown       |
| 10260 | 4/1/22 09:14  | Manor 2                                    | Voltage Sag  | unknown       |
| 10261 | 3/31/22 8:05  | Newburgh - Peru                            | Voltage Sag  | weather       |
| 10261 | 8/30/22 16:59 | Monroe - Lallendorf                        | Voltage Sag  | line equip    |
| 10262 | 3/6/22 12:53  | Northwest Trunk 2443-44                    | Voltage Sag  | weather       |
| 10262 | 3/6/22 13:24  | Northwest Trunk 2443-44                    | Voltage Sag  | weather       |
| 10262 | 3/7/22 22:02  | Northwest Trunk 2427-28                    | Voltage Sag  | line equip    |
| 10262 | 3/10/22 15:39 | Northwest Trunk 2411                       | Voltage Sag  | interference  |
| 10262 | 4/14/22 18:53 | Northwest Trunk 2443                       | Voltage Sag  | weather       |
| 10262 | 4/15/22 21:19 | Northwest Trunk 2411                       | Voltage Sag  | weather       |
| 10262 | 5/8/22 7:40   | Northwest Bus 2                            | Voltage Sag  | station equip |
| 10262 | 5/12/22 18:54 | Warren Trunk 612                           | Interruption | conductor     |
| 10262 | 7/10/22 18:33 | Northwest Trunk 2466                       | Voltage Sag  | unknown       |

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|       |               |                                            |              |               |
|-------|---------------|--------------------------------------------|--------------|---------------|
| 10262 | 7/15/22 19:21 | River Rouge - Warren 2                     | Voltage Sag  | Interference  |
| 10262 | 8/30/22 7:24  | Northwest Trunk 2439                       | Voltage Sag  | weather       |
| 10263 | 7/15/22 19:21 | River Rouge - Warren 2                     | Voltage Sag  | Interference  |
| 10264 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10264 | 4/10/22 12:27 | Imlay City Tie 3220                        | Voltage Sag  | unknown       |
| 10264 | 7/8/22 6:07   | Wabash Trunk 6854                          | Voltage Sag  | unknown       |
| 10264 | 7/12/22 22:34 | Wabash Trunk 6854                          | Voltage Sag  | conductor     |
| 10264 | 7/13/22 2:01  | Wabash Trunk 6854                          | Voltage Sag  | intentional   |
| 10265 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10265 | 7/8/22 6:08   | Wabash Trunk 6854                          | Voltage Sag  | unknown       |
| 10265 | 7/12/22 22:34 | Wabash Trunk 6854                          | Voltage Sag  | conductor     |
| 10265 | 7/13/22 2:02  | Wabash Trunk 6854                          | Voltage Sag  | intentional   |
| 10266 | 2/19/22 15:17 | Argo - Superior 1531                       | Voltage Sag  | unknown       |
| 10266 | 2/20/22 11:55 | Superior Trunk 1525                        | Voltage Sag  | conductor     |
| 10266 | 4/3/22 15:51  | Superior                                   | Voltage Sag  | unknown       |
| 10266 | 4/9/22 3:25   | Superior Trunk 1527                        | Voltage Sag  | unknown       |
| 10266 | 4/18/22 8:59  | Limited Data to identify affected elements | Voltage Sag  | customer      |
| 10266 | 4/28/22 0:25  | Carpenter - Superior 1568                  | Voltage Sag  | unknown       |
| 10266 | 7/28/22 17:16 | Superior Trunk 1502                        | Voltage Sag  | unknown       |
| 10266 | 9/3/22 12:03  | Superior Trunk 1502                        | Voltage Sag  | weather       |
| 10266 | 9/20/22 17:50 | Lark Tie 5513                              | Voltage Sag  | unknown       |
| 10266 | 10/2/22 14:07 | Coral                                      | Interruption | unknown       |
| 10266 | 9/25/22 10:04 | Coral                                      | Interruption | station equip |
| 10267 | 2/15/22 10:03 | Hunters Creek Tie 9111                     | Voltage Sag  | conductor     |
| 10267 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10267 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10267 | 4/14/22 17:19 | Carpenter - Superior 1568                  | Voltage Sag  | line equip    |
| 10267 | 4/14/22 21:38 | Carpenter - Superior 1568                  | Voltage Sag  | weather       |
| 10267 | 5/27/22 3:31  | Carpenter - Superior 1568                  | Voltage Sag  | interference  |
| 10267 | 6/3/22 20:05  | Pontiac-Placid                             | Voltage Sag  | station equip |
| 10267 | 6/3/22 20:23  | Pontiac-Placid                             | Voltage Sag  | station equip |
| 10267 | 6/14/22 1:29  | Carpenter - Luzon 3705                     | Voltage Sag  | unknown       |
| 10267 | 4/1/22 09:14  | Ortonville 1                               | Voltage Sag  | unknown       |
| 10268 | 4/3/22 15:52  | Superior                                   | Voltage Sag  | unknown       |
| 10268 | 4/14/22 18:36 | Argo - Phoenix 5517                        | Voltage Sag  | weather       |
| 10268 | 7/28/22 17:16 | Superior Trunk 1502                        | Voltage Sag  | unknown       |
| 10268 | 8/31/22 9:05  | Phoenix Tie 5513                           | Voltage Sag  | weather       |
| 10268 | 8/31/22 13:59 | Phoenix Tie 5513                           | Voltage Sag  | weather       |
| 10268 | 9/20/22 17:50 | Phoenix Tie 5513                           | Voltage Sag  | unknown       |
| 10269 | 1/7/22 12:17  | Wheeler Transformer 2                      | Voltage Sag  | station equip |
| 10269 | 1/7/22 12:17  | Wheeler Transformer 2                      | Voltage Sag  | station equip |
| 10269 | 1/22/22 17:51 | Northeast Trunk 448                        | Voltage Sag  | conductor     |
| 10269 | 1/22/22 18:26 | Northeast Trunk 448                        | Voltage Sag  | conductor     |
| 10269 | 2/17/22 22:39 | River Rouge - Navarre                      | Voltage Sag  | weather       |
| 10269 | 3/4/22 15:49  | Northeast Trunk 467T                       | Voltage Sag  | conductor     |
| 10269 | 3/9/22 15:06  | Northeast Trunk 467T                       | Interruption | line equip    |

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|-------|---------------|--------------------------------------------|--------------|---------------|
| 10269 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10269 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10269 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10269 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10269 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10269 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10269 | 5/26/22 17:30 | Coventry - Wixom                           | Interruption | weather       |
| 10269 | 6/6/22 4:33   | Northeast Trunk 467                        | Voltage Sag  | unknown       |
| 10269 | 7/10/22 8:31  | Northeast Trunk 467                        | Voltage Sag  | interference  |
| 10269 | 7/25/22 17:54 | Logan Transformer 2                        | Voltage Sag  | station equip |
| 10269 | 7/25/22 19:57 | Logan Transformer 2                        | Voltage Sag  | station equip |
| 10269 | 7/25/22 21:25 | Logan Transformer 2                        | Voltage Sag  | station equip |
| 10269 | 7/25/22 23:44 | Logan Transformer 2                        | Voltage Sag  | station equip |
| 10269 | 7/26/22 1:49  | Logan Transformer 2                        | Voltage Sag  | station equip |
| 10269 | 7/26/22 5:35  | Logan Transformer 2                        | Voltage Sag  | station equip |
| 10269 | 7/26/22 6:21  | Logan Transformer 2                        | Voltage Sag  | station equip |
| 10269 | 7/26/22 6:46  | Logan Transformer 2                        | Voltage Sag  | station equip |
| 10269 | 7/26/22 8:11  | Logan Transformer 2                        | Voltage Sag  | station equip |
| 10269 | 7/26/22 9:22  | Logan Transformer 2                        | Voltage Sag  | station equip |
| 10269 | 7/26/22 10:08 | Logan Transformer 2                        | Voltage Sag  | station equip |
| 10269 | 7/26/22 10:24 | Logan Transformer 2                        | Voltage Sag  | station equip |
| 10269 | 7/26/22 11:37 | Logan Transformer 2                        | Voltage Sag  | station equip |
| 10269 | 7/26/22 12:19 | Logan Transformer 2                        | Voltage Sag  | station equip |
| 10269 | 7/26/22 13:30 | Logan Transformer 2                        | Voltage Sag  | station equip |
| 10269 | 7/26/22 15:13 | Logan Transformer 2                        | Voltage Sag  | station equip |
| 10269 | 7/26/22 16:27 | Logan Transformer 2                        | Voltage Sag  | station equip |
| 10269 | 7/26/22 17:00 | Logan Transformer 2                        | Voltage Sag  | station equip |
| 10269 | 7/26/22 17:36 | Logan Transformer 2                        | Voltage Sag  | station equip |
| 10269 | 7/26/22 19:27 | Logan Transformer 2                        | Voltage Sag  | station equip |
| 10269 | 8/31/22 8:08  | Bloomfield - Walton                        | Voltage Sag  | intentional   |
| 10269 | 4/1/22 09:14  | Vandyke 1                                  | Voltage Sag  | unknown       |
| 10270 | 1/2/22 10:57  | Frisbee Trunk 1872                         | Voltage Sag  | station equip |
| 10270 | 1/7/22 12:17  | Wheeler Transformer 2                      | Voltage Sag  | station equip |
| 10270 | 4/6/22 23:47  | Bloomfield                                 | Voltage Sag  | unknown       |
| 10270 | 4/7/22 2:51   | Bloomfield-Walton                          | Voltage Sag  | unknown       |
| 10270 | 4/7/22 4:05   | Bloomfield-Walton                          | Voltage Sag  | unknown       |
| 10270 | 4/24/22 14:39 | Walton - Trunk 2636                        | Voltage Sag  | conductor     |
| 10270 | 5/9/22 7:47   | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10270 | 5/25/22 20:59 | Frisbee - Trunk 1862-ST                    | Voltage Sag  | conductor     |
| 10270 | 5/26/22 9:07  | Frisbee - Trunk 1856                       | Voltage Sag  | conductor     |
| 10270 | 7/27/22 13:27 | Bloomfield Tie 1268                        | Voltage Sag  | conductor     |
| 10270 | 9/22/22 2:44  | Walton Capacitor 2                         | Voltage Sag  | station equip |
| 10270 | 9/22/22 02:44 | Walton Capacitor 2                         | Voltage Sag  | station equip |
| 10271 | 1/22/22 17:51 | Northeast Trunk 448                        | Voltage Sag  | conductor     |
| 10271 | 1/22/22 18:26 | Northeast Trunk 448                        | Voltage Sag  | conductor     |
| 10271 | 3/9/22 15:06  | Northeast Trunk 467T                       | Interruption | line equip    |

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|-------|---------------|--------------------------------------------|--------------|--------------|
| 10271 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather      |
| 10271 | 5/21/22 10:06 | Limited Data to identify affected elements | Voltage Sag  | unknown      |
| 10271 | 6/6/22 4:33   | Northeast Trunk 467                        | Voltage Sag  | unknown      |
| 10271 | 7/10/22 8:30  | Northeast Trunk 467                        | Voltage Sag  | interference |
| 10272 | 2/17/22 22:13 | Topaz Transformer 1                        | Voltage Sag  | customer     |
| 10272 | 2/17/22 22:39 | River Rouge - Navarre                      | Voltage Sag  | weather      |
| 10272 | 2/17/22 22:39 | River Rouge - Navarre                      | Voltage Sag  | weather      |
| 10272 | 2/17/22 22:39 | River Rouge - Navarre                      | Voltage Sag  | weather      |
| 10272 | 2/17/22 22:40 | River Rouge - Navarre                      | Voltage Sag  | weather      |
| 10272 | 2/27/22 12:13 | Fuson Transformer 2                        | Interruption | customer     |
| 10272 | 2/28/22 16:31 | Limited Data to identify affected elements | Interruption | customer     |
| 10272 | 3/13/22 9:46  | Brock Trunk 8407                           | Voltage Sag  | conductor    |
| 10272 | 3/24/22 13:05 | Limited Data to identify affected elements | Voltage Sag  | unknown      |
| 10272 | 3/30/22 6:07  | Coventry - Wixom                           | Voltage Sag  | weather      |
| 10272 | 3/31/22 8:04  | Newburgh - Peru                            | Voltage Sag  | weather      |
| 10272 | 3/31/22 8:05  | Newburgh - Peru                            | Voltage Sag  | weather      |
| 10272 | 3/31/22 8:05  | Newburgh - Peru                            | Voltage Sag  | weather      |
| 10272 | 3/31/22 8:05  | Newburgh - Peru                            | Voltage Sag  | weather      |
| 10272 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather      |
| 10272 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather      |
| 10272 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather      |
| 10272 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather      |
| 10272 | 4/24/22 14:25 | Limited Data to identify affected elements | Interruption | unknown      |
| 10272 | 5/13/22 6:21  | Sterling Trunk 2742                        | Voltage Sag  | conductor    |
| 10272 | 5/18/22 9:17  | Limited Data to identify affected elements | Voltage Sag  | unknown      |
| 10272 | 5/19/22 12:21 | Limited Data to identify affected elements | Voltage Sag  | unknown      |
| 10272 | 6/14/22 20:51 | Limited Data to identify affected elements | Voltage Sag  | unknown      |
| 10272 | 6/15/22 13:25 | Limited Data to identify affected elements | Voltage Sag  | unknown      |
| 10272 | 6/16/22 8:54  | Limited Data to identify affected elements | Voltage Sag  | unknown      |
| 10272 | 6/16/22 9:20  | Brownstown - Berlin                        | Voltage Sag  | weather      |
| 10272 | 6/16/22 9:20  | Brownstown - Berlin                        | Voltage Sag  | weather      |
| 10272 | 6/16/22 9:20  | Brownstown - Berlin                        | Voltage Sag  | weather      |
| 10272 | 6/16/22 9:20  | Brownstown - Berlin                        | Voltage Sag  | weather      |
| 10272 | 6/16/22 9:21  | Brownstown - Berlin                        | Interruption | weather      |
| 10272 | 6/16/22 9:22  | Brownstown - Berlin                        | Voltage Sag  | weather      |
| 10272 | 6/24/22 23:38 | Limited Data to identify affected elements | Voltage Sag  | Interference |
| 10272 | 7/15/22 18:54 | Limited Data to identify affected elements | Voltage Sag  | unknown      |

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|-------|----------------|--------------------------------------------|--------------|---------------|
| 10272 | 7/15/22 19:21  | River Rouge - Warren 2                     | Voltage Sag  | Interference  |
| 10272 | 7/15/22 19:21  | River Rouge - Warren 2                     | Voltage Sag  | Interference  |
| 10272 | 7/15/22 19:21  | River Rouge - Warren 2                     | Voltage Sag  | Interference  |
| 10272 | 7/15/22 19:21  | River Rouge - Warren 2                     | Voltage Sag  | Interference  |
| 10272 | 7/15/22 19:21  | River Rouge - Warren 2                     | Voltage Sag  | Interference  |
| 10272 | 7/31/22 8:25   | Monroe - Wayne                             | Voltage Sag  | line equip    |
| 10272 | 8/20/22 16:48  | Milan - Monroe Power Plant                 | Voltage Sag  | weather       |
| 10272 | 8/30/22 16:33  | Monroe - Lallendorf                        | Voltage Sag  | line equip    |
| 10272 | 8/30/22 16:56  | Monroe - Lallendorf                        | Voltage Sag  | line equip    |
| 10272 | 8/30/22 16:58  | Monroe - Lallendorf                        | Voltage Sag  | line equip    |
| 10272 | 8/30/22 16:59  | Monroe - Lallendorf                        | Voltage Sag  | line equip    |
| 10272 | 8/30/22 16:59  | Monroe - Lallendorf                        | Voltage Sag  | line equip    |
| 10272 | 8/30/22 16:59  | Monroe - Lallendorf                        | Voltage Sag  | line equip    |
| 10272 | 8/30/22 16:59  | Monroe - Lallendorf                        | Voltage Sag  | line equip    |
| 10272 | 8/30/22 17:00  | Monroe - Lallendorf                        | Voltage Sag  | line equip    |
| 10272 | 8/30/22 17:01  | Monroe - Lallendorf                        | Voltage Sag  | line equip    |
| 10272 | 9/6/22 11:22   | Keith - Waterman                           | Voltage Sag  | unknown       |
| 10272 | 9/12/22 6:05   | Brownstown - Navarre 2                     | Voltage Sag  | unknown       |
| 10272 | 9/19/22 5:56   | Sterling Trunk 2719                        | Voltage Sag  | unknown       |
| 10272 | 10/11/22 19:32 | Arrowhead                                  | Voltage Sag  | unknown       |
| 10272 | 10/11/22 19:32 | Arrowhead                                  | Voltage Sag  | unknown       |
| 10272 | 10/4/22 08:09  | Dayton TIE 7733                            | Voltage Sag  | unknown       |
| 10272 | 7/6/22 14:38   | Dayton - Romulus                           | Voltage Sag  | unknown       |
| 10272 | 7/6/22 15:26   | Dayton - Romulus                           | Voltage Sag  | unknown       |
| 10272 | 4/1/22 09:14   | Lowel 2                                    | Voltage Sag  | unknown       |
| 10272 | 4/1/22 09:14   | Mustang 1                                  | Voltage Sag  | unknown       |
| 10272 | 4/1/22 09:14   | Burns 2                                    | Voltage Sag  | unknown       |
| 10274 | 3/31/22 8:05   | Newburgh - Peru                            | Voltage Sag  | weather       |
| 10274 | 4/23/22 3:46   | Newburgh - Trunk 2002                      | Interruption | lightning     |
| 10274 | 6/1/22 12:22   | Newburgh-Romulus 2025                      | Voltage Sag  | weather       |
| 10274 | 6/1/22 12:44   | Newburgh-Romulus 2025                      | Voltage Sag  | weather       |
| 10274 | 6/1/22 22:01   | Newburgh Trunk 2087                        | Voltage Sag  | unknown       |
| 10274 | 7/24/22 0:37   | Newburgh - Truck 2027                      | Voltage Sag  | unknown       |
| 10274 | 7/24/22 9:11   | Omaha DC 8222                              | Voltage Sag  | unknown       |
| 10274 | 7/31/22 8:25   | Monroe - Wayne                             | Voltage Sag  | line equip    |
| 10274 | 8/8/22 8:33    | Newburgh Trunk 2027                        | Voltage Sag  | unknown       |
| 10274 | 8/21/22 3:41   | Newburgh Trunk 2027                        | Voltage Sag  | unknown       |
| 10274 | 9/5/22 14:31   | Newburg Trunk 2027                         | Voltage Sag  | conductor     |
| 10274 | 9/12/22 0:06   | Newburgh Trunk 2027                        | Voltage Sag  | line equip    |
| 10274 | 9/19/22 5:43   | Newburg Trunk 2027                         | Voltage Sag  | unknown       |
| 10274 | 9/20/22 23:49  | Omaha DC 9458                              | Voltage Sag  | station equip |
| 10274 | 7/6/22 14:39   | Dayton - Romulus                           | Voltage Sag  | unknown       |
| 10274 | 9/27/22 01:23  | Newburgh Trunk 2032                        | Voltage Sag  | unknown       |
| 10275 | 3/31/22 8:27   | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10275 | 4/1/22 09:14   | Gendy 1                                    | Voltage Sag  | unknown       |
| 10276 | 6/24/22 23:38  | Limited Data to identify affected elements | Voltage Sag  | Interference  |

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|       |               |                                            |              |               |
|-------|---------------|--------------------------------------------|--------------|---------------|
| 10276 | 8/20/22 16:51 | Milan - Monroe Power Plant                 | Voltage Sag  | weather       |
| 10277 | 1/3/22 2:04   | Bloomfield Trunk 1276                      | Voltage Sag  | unknown       |
| 10277 | 1/6/22 1:54   | Erin - Stephens                            | Voltage Sag  | station equip |
| 10277 | 1/7/22 12:17  | Wheeler Transformer 2                      | Voltage Sag  | station equip |
| 10277 | 1/7/22 12:17  | Wheeler Transformer 2                      | Voltage Sag  | station equip |
| 10277 | 1/7/22 12:17  | Wheeler Transformer 2                      | Voltage Sag  | station equip |
| 10277 | 1/9/22 2:06   | Stephens Trunk 2541                        | Voltage Sag  | unknown       |
| 10277 | 1/9/22 5:24   | Springwells Pumping Transformer 1          | Voltage Sag  | unknown       |
| 10277 | 1/10/22 9:03  | Springwells Pumping Transformer 1          | Voltage Sag  | unknown       |
| 10277 | 1/10/22 15:55 | Springwells Pumping Transformer 1          | Voltage Sag  | unknown       |
| 10277 | 1/11/22 8:17  | Spokane-Oxford 6931                        | Voltage Sag  | unknown       |
| 10277 | 1/11/22 18:04 | Springwells Pumping Transformer 1          | Voltage Sag  | unknown       |
| 10277 | 1/22/22 17:51 | Northeast Trunk 448                        | Voltage Sag  | conductor     |
| 10277 | 1/22/22 17:51 | Northeast Trunk 448                        | Voltage Sag  | conductor     |
| 10277 | 1/22/22 18:26 | Northeast Trunk 448                        | Voltage Sag  | conductor     |
| 10277 | 1/22/22 18:27 | Northeast Trunk 448                        | Voltage Sag  | conductor     |
| 10277 | 2/2/22 0:46   | Walton Bus 1                               | Voltage Sag  | station equip |
| 10277 | 2/9/22 16:13  | Limited Data to identify affected elements | Voltage Sag  | intentional   |
| 10277 | 2/11/22 10:30 | Phoenix Trunk 7150-51                      | Voltage Sag  | unknown       |
| 10277 | 2/11/22 10:30 | Phoenix Trunk 7150-51                      | Voltage Sag  | unknown       |
| 10277 | 2/17/22 5:13  | Springwells Pumping Transformer 1          | Voltage Sag  | customer      |
| 10277 | 2/17/22 17:37 | Springwells Pumping Transformer 1          | Voltage Sag  | customer      |
| 10277 | 2/17/22 22:39 | River Rouge - Navarre                      | Voltage Sag  | weather       |
| 10277 | 2/17/22 22:40 | River Rouge - Navarre                      | Voltage Sag  | weather       |
| 10277 | 2/22/22 5:22  | Springwells Pumping Transformer 1          | Voltage Sag  | customer      |
| 10277 | 2/22/22 6:50  | Springwells Pumping Transformer 1          | Voltage Sag  | customer      |
| 10277 | 2/24/22 5:55  | Springwells Pumping Transformer 1          | Voltage Sag  | customer      |
| 10277 | 2/25/22 5:37  | Springwells Pumping Transformer 1          | Voltage Sag  | unknown       |
| 10277 | 2/26/22 3:25  | Springwells Pumping Transformer 1          | Voltage Sag  | customer      |
| 10277 | 3/2/22 9:09   | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10277 | 3/4/22 11:06  | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10277 | 3/4/22 15:49  | Northeast Trunk 467T                       | Voltage Sag  | conductor     |
| 10277 | 3/4/22 15:50  | Northeast Trunk 467T                       | Voltage Sag  | conductor     |
| 10277 | 3/9/22 15:05  | Northeast Trunk 467T                       | Interruption | line equip    |
| 10277 | 3/9/22 15:06  | Northeast Trunk 467T                       | Interruption | line equip    |
| 10277 | 3/13/22 23:18 | Cortland Trunk 1719                        | Voltage Sag  | conductor     |
| 10277 | 3/16/22 15:53 | Limited Data to identify affected elements | Voltage Sag  | customer      |
| 10277 | 3/24/22 10:59 | Limited Data to identify affected elements | Interruption | unknown       |
| 10277 | 3/25/22 5:04  | Springwells Pumping Transformer 1          | Voltage Sag  | customer      |
| 10277 | 3/25/22 15:06 | Springwells Pumping Transformer 1          | Voltage Sag  | customer      |
| 10277 | 3/27/22 14:43 | Stephens Trunk 2523                        | Voltage Sag  | unknown       |
| 10277 | 3/28/22 12:55 | Limited Data to identify affected elements | Interruption | unknown       |



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|       |               |                                            |              |               |
|-------|---------------|--------------------------------------------|--------------|---------------|
| 10277 | 3/30/22 6:07  | Coventry - Wixom                           | Voltage Sag  | weather       |
| 10277 | 3/30/22 6:07  | Coventry - Wixom                           | Voltage Sag  | weather       |
| 10277 | 3/30/22 6:07  | Coventry - Wixom                           | Voltage Sag  | weather       |
| 10277 | 3/31/22 8:05  | Newburgh - Peru                            | Voltage Sag  | weather       |
| 10277 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10277 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10277 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10277 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10277 | 3/31/22 8:28  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10277 | 4/6/22 23:46  | Bloomfield                                 | Voltage Sag  | unknown       |
| 10277 | 4/7/22 2:52   | Bloomfield-Walton                          | Voltage Sag  | unknown       |
| 10277 | 4/7/22 4:05   | Bloomfield-Walton                          | Voltage Sag  | unknown       |
| 10277 | 4/11/22 11:09 | Bloomfield Trunk 1232                      | Voltage Sag  | line equip    |
| 10277 | 4/14/22 2:12  | Waterman Trunk 720                         | Voltage Sag  | conductor     |
| 10277 | 4/14/22 4:23  | Spokane Trunk 6919                         | Voltage Sag  | weather       |
| 10277 | 4/16/22 8:39  | Limited Data to identify affected elements | Voltage Sag  | customer      |
| 10277 | 4/17/22 8:35  | Limited Data to identify affected elements | Voltage Sag  | customer      |
| 10277 | 4/17/22 21:06 | Limited Data to identify affected elements | Voltage Sag  | customer      |
| 10277 | 4/18/22 11:04 | Limited Data to identify affected elements | Voltage Sag  | customer      |
| 10277 | 4/18/22 16:49 | Oxford - Spokane Tie 6931                  | Voltage Sag  | unknown       |
| 10277 | 4/19/22 11:14 | Springwells Pumping Transformer            | Interruption | customer      |
| 10277 | 4/20/22 0:29  | Limited Data to identify affected elements | Voltage Sag  | customer      |
| 10277 | 4/23/22 3:46  | Newburgh - Trunk 2002                      | Interruption | lightning     |
| 10277 | 4/24/22 14:39 | Walton - Trunk 2636                        | Voltage Sag  | conductor     |
| 10277 | 4/24/22 16:47 | Omaha DC 9458                              | Voltage Sag  | unknown       |
| 10277 | 5/12/22 17:37 | Bloomfield Trunk 1225                      | Voltage Sag  | unknown       |
| 10277 | 5/16/22 9:53  | Limited Data to identify affected elements | Voltage Sag  | customer      |
| 10277 | 5/16/22 12:43 | Hager - Sunset                             | Voltage Sag  | intentional   |
| 10277 | 5/17/22 3:15  | Essex Trunk 570                            | Voltage Sag  | conductor     |
| 10277 | 5/17/22 3:15  | Essex Trunk 570                            | Voltage Sag  | conductor     |
| 10277 | 5/17/22 5:07  | Limited Data to identify affected elements | Voltage Sag  | customer      |
| 10277 | 5/17/22 6:02  | Limited Data to identify affected elements | Voltage Sag  | customer      |
| 10277 | 5/20/22 17:10 | Hines Trunk 2918                           | Voltage Sag  | unknown       |
| 10277 | 5/24/22 10:43 | Spokane Trunk 6919                         | Voltage Sag  | interference  |
| 10277 | 5/24/22 12:03 | Spokane Trunk 6919                         | Voltage Sag  | interference  |
| 10277 | 5/27/22 11:34 | Essex - Trunk 539-S                        | Voltage Sag  | unknown       |
| 10277 | 5/27/22 11:34 | Essex - Trunk 539-S                        | Voltage Sag  | unknown       |
| 10277 | 6/1/22 12:31  | Newburgh-Romulus 2025                      | Voltage Sag  | weather       |
| 10277 | 6/1/22 12:45  | Newburgh-Romulus 2025                      | Voltage Sag  | weather       |
| 10277 | 6/3/22 20:05  | Pontiac-Placid                             | Voltage Sag  | station equip |

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|       |                |                                            |             |               |
|-------|----------------|--------------------------------------------|-------------|---------------|
| 10277 | 6/3/22 20:22   | Pontiac-Placid                             | Voltage Sag | station equip |
| 10277 | 6/3/22 20:23   | Pontiac-Placid                             | Voltage Sag | station equip |
| 10277 | 6/6/22 4:33    | Northeast Trunk 467                        | Voltage Sag | unknown       |
| 10277 | 6/6/22 4:34    | Northeast Trunk 467                        | Voltage Sag | unknown       |
| 10277 | 6/13/22 18:40  | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10277 | 6/14/22 8:48   | Spokane Trunk 6919                         | Voltage Sag | interference  |
| 10277 | 6/16/22 9:21   | Brownstown - Berlin                        | Voltage Sag | weather       |
| 10277 | 6/16/22 9:21   | Brownstown - Berlin                        | Voltage Sag | weather       |
| 10277 | 6/16/22 9:21   | Brownstown - Berlin                        | Voltage Sag | weather       |
| 10277 | 6/16/22 10:55  | Waterman Trunk 722T                        | Voltage Sag | conductor     |
| 10277 | 6/17/22 22:56  | Waterman Tie 189                           | Voltage Sag | conductor     |
| 10277 | 6/23/22 19:11  | Bell Creek DC 8011                         | Voltage Sag | interference  |
| 10277 | 6/26/22 8:47   | Southfield Trunk 7106                      | Voltage Sag | unknown       |
| 10277 | 6/30/22 6:48   | Southfield Trunk 7122                      | Voltage Sag | intentional   |
| 10277 | 7/8/22 1:08    | Jewell-Puttygut                            | Voltage Sag | unknown       |
| 10277 | 7/8/22 19:25   | Cortland Trunk 1761-62                     | Voltage Sag | conductor     |
| 10277 | 7/10/22 8:30   | Northeast Trunk 467                        | Voltage Sag | interference  |
| 10277 | 7/10/22 8:31   | Northeast Trunk 467                        | Voltage Sag | interference  |
| 10277 | 7/14/22 12:44  | Cortland Trunk 1728                        | Voltage Sag | conductor     |
| 10277 | 7/15/22 19:21  | River Rouge - Warren 2                     | Voltage Sag | Interference  |
| 10277 | 7/16/22 9:01   | Southfield Trunk 7122                      | Voltage Sag | unknown       |
| 10277 | 7/17/22 14:56  | Gary                                       | Voltage Sag | unknown       |
| 10277 | 7/17/22 14:56  | Gary                                       | Voltage Sag | unknown       |
| 10277 | 7/24/22 0:19   | Newburgh - Trunk 2016                      | Voltage Sag | unknown       |
| 10277 | 7/24/22 0:37   | Newburgh - Truck 2027                      | Voltage Sag | unknown       |
| 10277 | 7/24/22 9:12   | Omaha DC 8222                              | Voltage Sag | unknown       |
| 10277 | 7/25/22 7:52   | Davis DC 8202                              | Voltage Sag | interference  |
| 10277 | 8/8/22 8:34    | Newburgh Trunk 2027                        | Voltage Sag | unknown       |
| 10277 | 8/10/22 8:31   | Spokane Trunk 6941                         | Voltage Sag | unknown       |
| 10277 | 8/16/22 7:03   | Spokane Capacitor 2                        | Voltage Sag | station equip |
| 10277 | 8/29/22 19:44  | Sunset - Trunk 5923                        | Voltage Sag | conductor     |
| 10277 | 8/30/22 16:59  | Monroe - Lallendorf                        | Voltage Sag | line equip    |
| 10277 | 8/30/22 16:59  | Monroe - Lallendorf                        | Voltage Sag | line equip    |
| 10277 | 9/1/22 18:36   | Hancock Generation                         | Voltage Sag | station equip |
| 10277 | 9/5/22 14:32   | Newburg Trunk 2027                         | Voltage Sag | conductor     |
| 10277 | 9/12/22 0:06   | Newburgh Trunk 2027                        | Voltage Sag | line equip    |
| 10277 | 9/17/22 16:16  | Waterman Trunk 764                         | Voltage Sag | conductor     |
| 10277 | 9/19/22 5:44   | Newburg Trunk 2027                         | Voltage Sag | unknown       |
| 10277 | 9/19/22 19:27  | Waterman Trunk 0709                        | Voltage Sag | conductor     |
| 10277 | 9/20/22 9:58   | Southfield Trunk 7122                      | Voltage Sag | unknown       |
| 10277 | 9/20/22 10:51  | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10277 | 9/20/22 23:50  | Omaha DC 9458 and DC 8222                  | Voltage Sag | station equip |
| 10277 | 9/22/22 2:44   | Walton Capacitor 2                         | Voltage Sag | station equip |
| 10277 | 10/11/22 18:21 | Arrowhead                                  | Voltage Sag | unknown       |
| 10277 | 10/11/22 18:21 | Arrowhead                                  | Voltage Sag | unknown       |

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|       |                |                                            |              |               |
|-------|----------------|--------------------------------------------|--------------|---------------|
| 10277 | 10/19/22 14:13 | Omaha DC 8233                              | Voltage Sag  | line equip    |
| 10277 | 10/2/22 09:3   | Bloomfield Trunk 1276                      | Voltage Sag  | unknown       |
| 10277 | 10/5/22 11:48  | Jewell - Stephens                          | Voltage Sag  | unknown       |
| 10277 | 10/5/22 14:53  | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10277 | 10/5/22 15:28  | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10277 | 10/5/22 19:43  | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10277 | 10/5/22 23:54  | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10277 | 7/6/22 11:44   | Rockwood                                   | Voltage Sag  | unknown       |
| 10277 | 7/6/22 11:44   | Rockwood                                   | Voltage Sag  | unknown       |
| 10277 | 7/6/22 14:39   | Dayton - Romulus                           | Voltage Sag  | unknown       |
| 10277 | 7/6/22 16:06   | Dayton - Romulus                           | Voltage Sag  | unknown       |
| 10277 | 9/22/22 02:44  | Walton Capacitor 2                         | Voltage Sag  | station equip |
| 10277 | 9/22/22 06:34  | Southfield Trunk 7150                      | Voltage Sag  | unknown       |
| 10277 | 9/27/22 01:24  | Newburgh Trunk 2032                        | Voltage Sag  | unknown       |
| 10277 | 9/27/22 10:40  | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10277 | 4/1/22 09:14   | Northeast Pumping 3                        | Voltage Sag  | unknown       |
| 10277 | 4/1/22 09:14   | Imlay City                                 | Voltage Sag  | unknown       |
| 10277 | 4/1/22 09:14   | Northeast Pumping 5                        | Voltage Sag  | unknown       |
| 10277 | 4/1/22 09:15   | Lake Huron Pumping 1                       | Voltage Sag  | unknown       |
| 10278 | 1/7/22 12:17   | Wheeler Transformer 2                      | Voltage Sag  | station equip |
| 10278 | 1/7/22 12:17   | Wheeler Transformer 2                      | Voltage Sag  | station equip |
| 10278 | 1/22/22 17:51  | Northeast Trunk 448                        | Voltage Sag  | conductor     |
| 10278 | 1/22/22 18:27  | Northeast Trunk 448                        | Voltage Sag  | conductor     |
| 10278 | 2/17/22 22:40  | River Rouge - Navarre                      | Voltage Sag  | weather       |
| 10278 | 2/17/22 22:41  | River Rouge - Navarre                      | Voltage Sag  | weather       |
| 10278 | 3/3/22 14:25   | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10278 | 3/4/22 15:50   | Northeast Trunk 467T                       | Voltage Sag  | conductor     |
| 10278 | 3/9/22 15:06   | Northeast Trunk 467T                       | Interruption | line equip    |
| 10278 | 3/30/22 6:07   | Coventry - Wixom                           | Voltage Sag  | weather       |
| 10278 | 3/31/22 8:05   | Newburgh - Peru                            | Voltage Sag  | weather       |
| 10278 | 3/31/22 8:05   | Newburgh - Peru                            | Voltage Sag  | weather       |
| 10278 | 3/31/22 8:27   | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10278 | 3/31/22 8:27   | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10278 | 4/14/22 18:39  | Argo - Phoenix 5517                        | Voltage Sag  | weather       |
| 10278 | 4/23/22 3:46   | Limited Data to identify affected elements | Voltage Sag  | customer      |
| 10278 | 4/29/22 8:35   | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10278 | 5/14/22 11:14  | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10278 | 5/15/22 9:49   | Limited Data to identify affected elements | Voltage Sag  | unknown       |

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|-------|---------------|--------------------------------------------|--------------|---------------|
| 10278 | 5/26/22 13:38 | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10278 | 6/1/22 12:31  | Newburgh-Romulus 2025                      | Voltage Sag  | weather       |
| 10278 | 6/1/22 12:45  | Newburgh-Romulus 2025                      | Voltage Sag  | weather       |
| 10278 | 6/1/22 22:01  | Newburgh Trunk 2087                        | Voltage Sag  | unknown       |
| 10278 | 6/3/22 20:05  | Pontiac-Placid                             | Voltage Sag  | station equip |
| 10278 | 6/3/22 20:05  | Pontiac-Placid                             | Voltage Sag  | station equip |
| 10278 | 6/3/22 20:06  | Pontiac-Placid                             | Voltage Sag  | station equip |
| 10278 | 6/3/22 20:22  | Pontiac-Placid                             | Voltage Sag  | station equip |
| 10278 | 6/3/22 20:22  | Pontiac-Placid                             | Voltage Sag  | station equip |
| 10278 | 6/5/22 8:32   | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10278 | 6/6/22 4:34   | Northeast Trunk 467                        | Voltage Sag  | unknown       |
| 10278 | 6/16/22 9:21  | Brownstown - Berlin                        | Voltage Sag  | weather       |
| 10278 | 6/16/22 9:22  | Brownstown - Berlin                        | Voltage Sag  | weather       |
| 10278 | 6/19/22 8:51  | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10278 | 6/24/22 23:39 | Limited Data to identify affected elements | Voltage Sag  | Interference  |
| 10278 | 7/9/22 12:01  | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10278 | 7/10/22 8:31  | Northeast Trunk 467                        | Voltage Sag  | interference  |
| 10278 | 7/11/22 6:25  | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10278 | 7/15/22 19:21 | River Rouge - Warren 2                     | Voltage Sag  | Interference  |
| 10278 | 7/31/22 8:25  | Monroe - Wayne                             | Voltage Sag  | line equip    |
| 10278 | 8/21/22 10:42 | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10278 | 8/30/22 16:59 | Monroe - Lallendorf                        | Voltage Sag  | line equip    |
| 10278 | 8/30/22 17:01 | Monroe - Lallendorf                        | Voltage Sag  | line equip    |
| 10278 | 9/5/22 14:31  | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10278 | 9/21/22 14:51 | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10278 | 7/6/22 14:39  | Dayton - Romulus                           | Voltage Sag  | unknown       |
| 10278 | 4/1/22 09:14  | Martin 2                                   | Voltage Sag  | unknown       |
| 10279 | 3/31/22 8:05  | Newburgh - Peru                            | Voltage Sag  | weather       |
| 10279 | 4/27/22 10:51 | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10280 | 3/6/22 9:11   | Brownstown - Rockwood 1318                 | Voltage Sag  | weather       |
| 10280 | 3/21/22 8:44  | Custer - Fleming Tie 1467                  | Voltage Sag  | unknown       |
| 10280 | 5/18/22 21:07 | Fleming - Rockwood Tie 8804                | Voltage Sag  | unknown       |
| 10280 | 5/20/22 17:18 | Fleming - Rockwood Tie 8804                | Voltage Sag  | unknown       |
| 10280 | 7/20/22 14:57 | Fleming - Romulus Tie 7702                 | Voltage Sag  | weather       |
| 10280 | 7/21/22 19:12 | Brownstown Trunk 1322                      | Voltage Sag  | line equip    |
| 10280 | 8/21/22 10:18 | Limited Data to identify affected elements | Interruption | unknown       |
| 10280 | 9/2/22 18:08  | Custer - Fleming Tie 1467                  | Voltage Sag  | conductor     |

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|       |               |                                            |              |               |
|-------|---------------|--------------------------------------------|--------------|---------------|
| 10280 | 7/6/22 11:15  | Rockwood                                   | Voltage Sag  | unknown       |
| 10280 | 7/6/22 14:38  | Dayton - Romulus                           | Voltage Sag  | unknown       |
| 10280 | 7/6/22 15:26  | Dayton - Romulus                           | Voltage Sag  | unknown       |
| 10281 | 1/10/22 15:58 | Hancock - Proud 4412                       | Voltage Sag  | unknown       |
| 10281 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10281 | 4/14/22 14:57 | Hancock - Proud 4412                       | Voltage Sag  | weather       |
| 10281 | 6/3/22 20:05  | Pontiac-Placid                             | Voltage Sag  | station equip |
| 10281 | 6/3/22 20:22  | Pontiac-Placid                             | Voltage Sag  | station equip |
| 10281 | 9/1/22 18:37  | Hancock Generation                         | Interruption | station equip |
| 10282 | 1/7/22 12:17  | Wheeler Transformer 2                      | Voltage Sag  | station equip |
| 10282 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10283 | 3/6/22 8:13   | Port Austin-Pigeon                         | Voltage Sag  | weather       |
| 10283 | 3/26/22 4:10  | Bad Axe-Tie 3410                           | Voltage Sag  | station equip |
| 10283 | 3/26/22 14:07 | Bad Axe-Tie 3410                           | Voltage Sag  | station equip |
| 10283 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10283 | 3/31/22 10:24 | Port Austin - Tie 3205                     | Voltage Sag  | weather       |
| 10283 | 3/31/22 10:40 | Port Austin - Tie 3205                     | Voltage Sag  | weather       |
| 10283 | 3/31/22 11:21 | Port Austin - Tie 3205                     | Voltage Sag  | weather       |
| 10283 | 3/31/22 11:38 | Port Austin - Tie 3205                     | Voltage Sag  | weather       |
| 10283 | 4/14/22 15:50 | Pigeon - Port Austin 3205                  | Voltage Sag  | weather       |
| 10283 | 4/14/22 16:19 | Pigeon - Port Austin 3205                  | Voltage Sag  | weather       |
| 10283 | 4/15/22 13:26 | Pigeon - Port Austin 3205                  | Voltage Sag  | weather       |
| 10284 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10285 | 4/2/22 23:39  | Romulus-Trenton                            | Voltage Sag  | unknown       |
| 10285 | 6/16/22 9:21  | Brownstown - Berlin                        | Voltage Sag  | weather       |
| 10285 | 6/24/22 23:38 | Limited Data to identify affected elements | Voltage Sag  | Interference  |
| 10285 | 8/30/22 16:59 | Monroe - Lallendorf                        | Voltage Sag  | line equip    |
| 10285 | 7/6/22 14:40  | Dayton - Romulus                           | Voltage Sag  | unknown       |
| 10285 | 7/6/22 15:27  | Dayton - Romulus                           | Voltage Sag  | unknown       |
| 10286 | 2/17/22 22:39 | River Rouge - Navarre                      | Voltage Sag  | weather       |
| 10286 | 2/17/22 22:40 | River Rouge - Navarre                      | Voltage Sag  | weather       |
| 10286 | 6/16/22 9:20  | Brownstown - Berlin                        | Voltage Sag  | weather       |
| 10286 | 6/16/22 9:21  | Brownstown - Berlin                        | Voltage Sag  | weather       |
| 10287 | 3/30/22 6:07  | Coventry - Wixom                           | Voltage Sag  | weather       |
| 10287 | 3/31/22 8:05  | Newburgh - Peru                            | Voltage Sag  | weather       |
| 10287 | 8/30/22 16:59 | Monroe - Lallendorf                        | Voltage Sag  | line equip    |
| 10288 | 1/7/22 12:16  | Wheeler Transformer 2                      | Voltage Sag  | station equip |
| 10288 | 2/11/22 20:08 | Troy Trunk 3511-12                         | Voltage Sag  | conductor     |
| 10288 | 3/1/22 13:53  | Troy Trunk 3540                            | Voltage Sag  | conductor     |
| 10288 | 3/31/22 8:26  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10288 | 4/14/22 16:18 | Savage DC 8146                             | Voltage Sag  | conductor     |
| 10288 | 4/14/22 19:23 | Savage DC 8146                             | Voltage Sag  | weather       |
| 10288 | 6/16/22 17:32 | Troy Trunk 3546                            | Voltage Sag  | conductor     |
| 10288 | 6/29/22 23:48 | Troy Trunk 3508-09                         | Voltage Sag  | conductor     |
| 10288 | 7/28/22 19:17 | Troy Trunk 3518                            | Voltage Sag  | unknown       |
| 10288 | 8/14/22 17:30 | Troy Trunk 3508                            | Voltage Sag  | conductor     |

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|-------|---------------|--------------------------------------------|--------------|---------------|
| 10288 | 9/19/22 5:45  | Troy Trunk 3557                            | Voltage Sag  | unknown       |
| 10289 | 5/17/22 9:12  | Evergreen Transformer 3                    | Voltage Sag  | station equip |
| 10289 | 7/15/22 19:20 | River Rouge - Warren 2                     | Voltage Sag  | Interference  |
| 10290 | 6/3/22 20:06  | Pontiac-Placid                             | Voltage Sag  | station equip |
| 10290 | 6/3/22 20:23  | Pontiac-Placid                             | Voltage Sag  | station equip |
| 10290 | 6/16/22 9:21  | Brownstown - Berlin                        | Voltage Sag  | weather       |
| 10290 | 6/24/22 23:39 | Limited Data to identify affected elements | Voltage Sag  | Interference  |
| 10290 | 7/8/22 1:08   | Jewell-Puttygut                            | Voltage Sag  | unknown       |
| 10290 | 7/15/22 19:21 | River Rouge - Warren 2                     | Voltage Sag  | Interference  |
| 10290 | 7/31/22 8:26  | Monroe - Wayne                             | Voltage Sag  | line equip    |
| 10290 | 8/15/22 10:24 | Akron-Wixom                                | Voltage Sag  | intentional   |
| 10291 | 3/31/22 8:05  | Newburgh - Peru                            | Voltage Sag  | weather       |
| 10291 | 8/30/22 16:59 | Monroe - Lallendorf                        | Voltage Sag  | line equip    |
| 10292 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10293 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10294 | 5/25/22 21:00 | Frisbee - Trunk 1862-ST                    | Voltage Sag  | conductor     |
| 10294 | 5/26/22 9:07  | Frisbee - Trunk 1856                       | Voltage Sag  | conductor     |
| 10296 | 2/17/22 22:39 | River Rouge - Navarre                      | Voltage Sag  | weather       |
| 10296 | 4/23/22 8:10  | Marathon Petro                             | Interruption | unknown       |
| 10296 | 4/25/22 13:06 | Marathon Petro                             | Interruption | unknown       |
| 10296 | 6/16/22 9:20  | Brownstown - Berlin                        | Voltage Sag  | weather       |
| 10296 | 6/16/22 9:21  | Brownstown - Berlin                        | Voltage Sag  | weather       |
| 10297 | 4/4/22 22:14  | Bunce Creek                                | Voltage Sag  | unknown       |
| 10297 | 4/1/22 09:15  | Simpson 1                                  | Voltage Sag  | unknown       |
| 10298 | 3/31/22 8:28  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10298 | 7/8/22 6:08   | Wabash Trunk 6854                          | Voltage Sag  | unknown       |
| 10298 | 7/12/22 22:34 | Wabash Trunk 6854                          | Voltage Sag  | conductor     |
| 10298 | 7/13/22 2:02  | Wabash Trunk 6854                          | Voltage Sag  | intentional   |
| 10298 | 4/1/22 09:15  | STDF 40                                    | Voltage Sag  | unknown       |
| 10299 | 3/31/22 8:05  | Newburgh - Peru                            | Voltage Sag  | weather       |
| 10299 | 3/31/22 8:05  | Newburgh - Peru                            | Voltage Sag  | weather       |
| 10299 | 3/31/22 8:05  | Newburgh - Peru                            | Voltage Sag  | weather       |
| 10299 | 3/31/22 8:05  | Newburgh - Peru                            | Voltage Sag  | weather       |
| 10300 | 3/8/22 7:11   | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10300 | 3/30/22 6:07  | Coventry - Wixom                           | Voltage Sag  | weather       |
| 10300 | 9/12/22 1:06  | Cody Trunk 2826                            | Voltage Sag  | unknown       |
| 10301 | 1/6/22 1:54   | Erin - Stephens                            | Voltage Sag  | station equip |
| 10301 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10301 | 10/5/22 11:47 | Stephens                                   | Voltage Sag  | unknown       |
| 10301 | 4/1/22 09:14  | Milkriver 2                                | Voltage Sag  | unknown       |
| 10302 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10302 | 9/19/22 5:57  | Sterling Trunk 2719                        | Voltage Sag  | unknown       |
| 10303 | 1/7/22 12:17  | Wheeler Transformer 2                      | Voltage Sag  | station equip |
| 10303 | 1/11/22 8:17  | Spokane-Oxford 6931                        | Voltage Sag  | unknown       |
| 10303 | 3/19/22 18:28 | Spokane Trunk 6938A-B                      | Voltage Sag  | unknown       |

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|-------|----------------|---------------------------|--------------|---------------|
| 10303 | 3/31/22 8:27   | Belle River Bus 302       | Voltage Sag  | weather       |
| 10303 | 4/14/22 4:23   | Spokane Trunk 6919        | Voltage Sag  | weather       |
| 10303 | 4/18/22 16:49  | Oxford - Spokane Tie 6931 | Voltage Sag  | unknown       |
| 10303 | 5/24/22 10:43  | Spokane Trunk 6919        | Voltage Sag  | interference  |
| 10303 | 5/24/22 12:03  | Spokane Trunk 6919        | Voltage Sag  | interference  |
| 10303 | 6/14/22 8:48   | Spokane Trunk 6919        | Voltage Sag  | interference  |
| 10303 | 8/10/22 8:31   | Spokane Trunk 6941        | Voltage Sag  | unknown       |
| 10303 | 8/16/22 7:03   | Spokane Capacitor 2       | Voltage Sag  | station equip |
| 10303 | 8/29/22 21:23  | Spokane - Tie 6907        | Voltage Sag  | line equip    |
| 10303 | 10/19/22 11:15 | Spokane Trunk 6941        | Voltage Sag  | line equip    |
| 10303 | 4/1/22 09:14   | ParkdaleL 2               | Voltage Sag  | unknown       |
| 10304 | 1/31/22 8:30   | Macomb Trunk 2305         | Voltage Sag  | unknown       |
| 10304 | 3/14/22 11:38  | Macomb Trunk 2305         | Voltage Sag  | unknown       |
| 10304 | 3/31/22 8:27   | Belle River Bus 302       | Voltage Sag  | weather       |
| 10304 | 6/7/22 6:58    | Benson Transformer 1      | Voltage Sag  | unknown       |
| 10304 | 7/8/22 1:07    | Jewell-Puttygut           | Voltage Sag  | unknown       |
| 10304 | 10/5/22 11:47  | Boyne DC 8406             | Voltage Sag  | unknown       |
| 10304 | 9/25/22 15:30  | Macomb Trunk 2301         | Interruption | unknown       |
| 10304 | 4/1/22 09:14   | STDF 32.8520              | Voltage Sag  | unknown       |
| 10305 | 6/16/22 9:20   | Brownstown - Berlin       | Voltage Sag  | weather       |
| 10305 | 8/30/22 16:59  | Monroe - Lallendorf       | Voltage Sag  | line equip    |
| 10306 | 3/31/22 8:05   | Newburgh - Peru           | Voltage Sag  | weather       |
| 10306 | 4/23/22 3:46   | Newburgh - Trunk 2002     | Interruption | lightning     |
| 10306 | 6/1/22 12:23   | Newburgh-Romulus 2025     | Voltage Sag  | weather       |
| 10306 | 6/1/22 12:45   | Newburgh-Romulus 2025     | Voltage Sag  | weather       |
| 10306 | 6/1/22 22:01   | Newburgh Trunk 2087       | Voltage Sag  | unknown       |
| 10306 | 7/24/22 0:37   | Newburgh - Truck 2027     | Voltage Sag  | unknown       |
| 10306 | 7/31/22 8:25   | Monroe - Wayne            | Voltage Sag  | line equip    |
| 10306 | 8/8/22 8:33    | Newburgh Trunk 2027       | Voltage Sag  | unknown       |
| 10306 | 9/5/22 14:31   | Newburg Trunk 2027        | Voltage Sag  | conductor     |
| 10306 | 9/12/22 0:06   | Newburgh Trunk 2027       | Voltage Sag  | line equip    |
| 10306 | 9/19/22 5:43   | Newburg Trunk 2027        | Voltage Sag  | unknown       |
| 10306 | 7/6/22 14:39   | Dayton - Romulus          | Voltage Sag  | unknown       |
| 10306 | 9/27/22 01:24  | Newburgh Trunk 2032       | Voltage Sag  | unknown       |
| 10307 | 6/15/22 23:21  | Waterman Trunk 722        | Voltage Sag  | weather       |
| 10307 | 9/17/22 16:20  | Waterman Trunk 764        | Voltage Sag  | conductor     |
| 10307 | 9/19/22 19:33  | Waterman Trunk 0709       | Interruption | conductor     |
| 10307 | 9/25/22 11:07  | Waterman Tie 185          | Interruption | unknown       |
| 10308 | 2/17/22 0:02   | Ironton                   | Voltage Sag  | customer      |
| 10308 | 2/17/22 22:39  | River Rouge - Navarre     | Voltage Sag  | weather       |
| 10308 | 2/17/22 22:40  | River Rouge - Navarre     | Voltage Sag  | weather       |
| 10308 | 6/16/22 9:20   | Brownstown - Berlin       | Voltage Sag  | weather       |
| 10308 | 6/16/22 9:21   | Brownstown - Berlin       | Voltage Sag  | weather       |
| 10308 | 7/17/22 8:21   | Ironton Trunk 3028        | Voltage Sag  | interference  |
| 10309 | 8/30/22 16:59  | Monroe - Lallendorf       | Voltage Sag  | line equip    |
| 10310 | 2/17/22 22:40  | River Rouge - Navarre     | Voltage Sag  | weather       |

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|-------|----------------|--------------------------------------------|--------------|---------------|
| 10310 | 3/31/22 8:40   | Riverview Trunk 5140                       | Voltage Sag  | weather       |
| 10310 | 8/21/22 21:01  | Riverview Trunk 5134                       | Voltage Sag  | unknown       |
| 10311 | 3/31/22 8:27   | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10311 | 3/31/22 13:13  | Boyne - Trunk 7913                         | Voltage Sag  | weather       |
| 10311 | 5/20/22 2:04   | Boyne Trunk 7913                           | Voltage Sag  | unknown       |
| 10311 | 9/3/22 14:33   | Chesterfield Transformer 1                 | Voltage Sag  | station equip |
| 10311 | 7/1/22 07:12   | Boyne Trunk 7909                           | Voltage Sag  | interference  |
| 10312 | 2/25/22 16:48  | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10312 | 6/15/22 20:28  | Arrowhead - Oliver 7520                    | Voltage Sag  | weather       |
| 10312 | 7/24/22 8:44   | Tuscola - Trunk 3304                       | Voltage Sag  | unknown       |
| 10313 | 2/17/22 22:39  | River Rouge - Navarre                      | Voltage Sag  | weather       |
| 10313 | 6/16/22 9:21   | Brownstown - Berlin                        | Voltage Sag  | weather       |
| 10314 | 4/6/22 23:46   | Bloomfield                                 | Interruption | unknown       |
| 10314 | 4/7/22 2:31    | Bloomfield-Walton                          | Interruption | unknown       |
| 10314 | 10/10/22 9:35  | Bloomfield-Walton                          | Interruption | unknown       |
| 10314 | 10/10/22 09:35 | Bloomfield - Walton                        | Interruption | unknown       |
| 10314 | 10/16/22 12:03 | Bloomfield Trunk 1280                      | Interruption | unknown       |
| 10314 | 9/27/22 09:33  | Bloomfield Trunk 1280                      | Interruption | unknown       |
| 10315 | 1/3/22 2:04    | Bloomfield Trunk 1276                      | Voltage Sag  | unknown       |
| 10315 | 1/7/22 12:17   | Wheeler Transformer 2                      | Voltage Sag  | station equip |
| 10315 | 2/2/22 0:46    | Walton Bus 1                               | Voltage Sag  | station equip |
| 10315 | 3/31/22 8:27   | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10315 | 4/7/22 2:51    | Bloomfield-Walton                          | Voltage Sag  | unknown       |
| 10315 | 4/7/22 4:04    | Bloomfield-Walton                          | Voltage Sag  | unknown       |
| 10315 | 4/11/22 11:09  | Bloomfield Trunk 1232                      | Voltage Sag  | line equip    |
| 10315 | 4/11/22 18:02  | Bloomfield Trunk 1232                      | Voltage Sag  | conductor     |
| 10315 | 4/12/22 0:59   | Bloomfield Trunk 1232                      | Voltage Sag  | unknown       |
| 10315 | 4/24/22 14:39  | Walton - Trunk 2636                        | Voltage Sag  | conductor     |
| 10315 | 5/12/22 17:36  | Bloomfield Trunk 1225                      | Voltage Sag  | unknown       |
| 10315 | 5/28/22 9:05   | Bloomfield Trunk 1229                      | Voltage Sag  | unknown       |
| 10315 | 6/3/22 20:05   | Pontiac-Placid                             | Voltage Sag  | station equip |
| 10315 | 6/3/22 20:22   | Pontiac-Placid                             | Voltage Sag  | station equip |
| 10315 | 7/27/22 13:27  | Bloomfield Tie 1268                        | Voltage Sag  | conductor     |
| 10315 | 9/22/22 2:43   | Walton Capacitor 2                         | Voltage Sag  | station equip |
| 10315 | 10/2/22 09:35  | Bloomfield Trunk 1276                      | Voltage Sag  | unknown       |
| 10315 | 9/22/22 02:43  | Walton Capacitor 2                         | Voltage Sag  | station equip |
| 10315 | 4/1/22 09:14   | Mercy 1                                    | Voltage Sag  | unknown       |
| 10316 | 7/15/22 19:21  | River Rouge - Warren 2                     | Interruption | Interference  |
| 10317 | 4/2/22 23:40   | Romulus-Trenton                            | Voltage Sag  | unknown       |
| 10317 | 6/16/22 9:21   | Brownstown - Berlin                        | Voltage Sag  | weather       |
| 10317 | 8/30/22 16:59  | Monroe - Lallendorf                        | Voltage Sag  | line equip    |
| 10317 | 7/6/22 14:40   | Dayton - Romulus                           | Voltage Sag  | unknown       |
| 10317 | 7/6/22 15:27   | Dayton - Romulus                           | Voltage Sag  | unknown       |
| 10318 | 3/31/22 8:05   | Newburgh - Peru                            | Voltage Sag  | weather       |
| 10318 | 3/31/22 8:27   | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10318 | 3/31/22 8:27   | Belle River Bus 302                        | Voltage Sag  | weather       |



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|-------|---------------|--------------------------------------------|--------------|------------|
| 10318 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather    |
| 10318 | 4/4/22 22:13  | Bunce Creek                                | Voltage Sag  | unknown    |
| 10318 | 4/23/22 3:46  | Newburgh - Trunk 2002                      | Voltage Sag  | lightning  |
| 10318 | 6/1/22 12:31  | Newburgh-Romulus 2025                      | Interruption | weather    |
| 10318 | 6/1/22 12:44  | Newburgh-Romulus 2025                      | Interruption | weather    |
| 10318 | 6/1/22 22:01  | Newburgh Trunk 2087                        | Interruption | unknown    |
| 10318 | 6/25/22 17:33 | Bunce Creek Tie 810                        | Voltage Sag  | line equip |
| 10318 | 7/11/22 17:19 | Newburgh Trunk 2005                        | Interruption | unknown    |
| 10318 | 7/24/22 0:19  | Newburgh - Trunk 2016                      | Voltage Sag  | unknown    |
| 10318 | 7/24/22 0:37  | Newburgh - Truck 2027                      | Voltage Sag  | unknown    |
| 10318 | 8/8/22 8:33   | Newburgh Trunk 2027                        | Voltage Sag  | unknown    |
| 10318 | 8/29/22 18:28 | Victor - Tie 4911                          | Voltage Sag  | weather    |
| 10318 | 8/30/22 16:59 | Monroe - Lallendorf                        | Voltage Sag  | line equip |
| 10318 | 9/5/22 14:31  | Newburg Trunk 2027                         | Voltage Sag  | conductor  |
| 10318 | 9/12/22 0:06  | Newburgh Trunk 2027                        | Voltage Sag  | line equip |
| 10318 | 9/19/22 5:43  | Newburg Trunk 2027                         | Voltage Sag  | unknown    |
| 10318 | 9/19/22 5:56  | Sterling Trunk 2719                        | Voltage Sag  | unknown    |
| 10318 | 12/3/22 7:40  | Newburgh Trunk 2005                        | Interruption | line equip |
| 10318 | 12/3/22 9:00  | Newburgh Trunk 2005                        | Interruption | line equip |
| 10318 | 12/3/22 18:43 | Newburgh Trunk 2005                        | Interruption | line equip |
| 10318 | 7/6/22 14:39  | Dayton - Romulus                           | Voltage Sag  | unknown    |
| 10318 | 7/6/22 17:21  | Dayton - Romulus                           | Voltage Sag  | unknown    |
| 10318 | 9/27/22 01:23 | Newburgh Trunk 2032                        | Voltage Sag  | unknown    |
| 10318 | 4/1/22 09:14  | Lemay 1                                    | Voltage Sag  | unknown    |
| 10319 | 2/2/22 10:28  | Limited Data to identify affected elements | Interruption | customer   |
| 10319 | 2/2/22 10:28  | Limited Data to identify affected elements | Voltage Sag  | customer   |
| 10319 | 2/2/22 10:28  | Limited Data to identify affected elements | Voltage Sag  | customer   |
| 10319 | 2/2/22 10:29  | Limited Data to identify affected elements | Interruption | customer   |
| 10319 | 2/2/22 11:20  | Limited Data to identify affected elements | Voltage Sag  | customer   |
| 10319 | 2/2/22 11:20  | Limited Data to identify affected elements | Voltage Sag  | customer   |
| 10319 | 2/2/22 12:54  | Limited Data to identify affected elements | Voltage Sag  | customer   |
| 10319 | 2/2/22 12:54  | Limited Data to identify affected elements | Voltage Sag  | customer   |
| 10319 | 2/2/22 14:53  | Limited Data to identify affected elements | Voltage Sag  | customer   |
| 10319 | 2/2/22 14:53  | Limited Data to identify affected elements | Voltage Sag  | customer   |
| 10319 | 2/2/22 14:53  | Limited Data to identify affected elements | Voltage Sag  | customer   |
| 10319 | 2/2/22 14:53  | Limited Data to identify affected elements | Interruption | customer   |

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|-------|---------------|--------------------------------------------|--------------|---------------|
| 10319 | 2/3/22 13:39  | Limited Data to identify affected elements | Voltage Sag  | customer      |
| 10319 | 2/3/22 13:39  | Limited Data to identify affected elements | Voltage Sag  | customer      |
| 10319 | 2/3/22 14:43  | Limited Data to identify affected elements | Voltage Sag  | customer      |
| 10319 | 2/3/22 14:43  | Limited Data to identify affected elements | Voltage Sag  | customer      |
| 10319 | 2/15/22 10:03 | Hunters Creek Tie 9111                     | Voltage Sag  | conductor     |
| 10319 | 3/6/22 8:13   | Port Austin-Pigeon                         | Voltage Sag  | weather       |
| 10319 | 3/6/22 8:24   | Derby-Tuscola 9123                         | Voltage Sag  | weather       |
| 10319 | 3/9/22 10:51  | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10319 | 3/26/22 4:09  | Bad Axe-Tie 3410                           | Voltage Sag  | station equip |
| 10319 | 3/26/22 14:07 | Bad Axe-Tie 3410                           | Voltage Sag  | station equip |
| 10319 | 3/27/22 9:15  | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10319 | 3/31/22 8:26  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10319 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10319 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10319 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10319 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10319 | 3/31/22 10:24 | Port Austin - Tie 3205                     | Voltage Sag  | weather       |
| 10319 | 3/31/22 10:40 | Port Austin - Tie 3205                     | Voltage Sag  | weather       |
| 10319 | 3/31/22 11:20 | Port Austin - Tie 3205                     | Voltage Sag  | weather       |
| 10319 | 3/31/22 11:38 | Port Austin - Tie 3205                     | Voltage Sag  | weather       |
| 10319 | 4/14/22 15:49 | Pigeon - Port Austin 3205                  | Voltage Sag  | weather       |
| 10319 | 4/14/22 16:19 | Pigeon - Port Austin 3205                  | Voltage Sag  | weather       |
| 10319 | 4/15/22 12:47 | Derby - Hunters Creek 9111                 | Voltage Sag  | weather       |
| 10319 | 4/15/22 13:34 | Pigeon - Port Austin 3205                  | Voltage Sag  | weather       |
| 10319 | 4/15/22 15:18 | Bad Axe - Sandusky - Wilmot 3417           | Voltage Sag  | weather       |
| 10319 | 4/24/22 18:32 | Bad Axe - Tie 3410                         | Voltage Sag  | weather       |
| 10319 | 5/14/22 17:35 | Pigeon - Randolph 3209                     | Voltage Sag  | unknown       |
| 10319 | 5/14/22 18:14 | Bad Axe - Sandusky - Wilmot 3417           | Voltage Sag  | unknown       |
| 10319 | 5/14/22 18:15 | Bad Axe - Sandusky - Wilmot 3417           | Voltage Sag  | unknown       |
| 10319 | 5/14/22 23:17 | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10319 | 5/14/22 23:17 | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10319 | 5/27/22 16:24 | Imlay City -Yale 3220                      | Interruption | unknown       |
| 10319 | 5/30/22 22:02 | Neff - Sandusky 4104                       | Interruption | unknown       |
| 10319 | 5/31/22 18:29 | Sandusky Tie 3417                          | Interruption | unknown       |
| 10319 | 6/11/22 21:23 | Bad Axe - Sandusky - Wilmot 3417           | Voltage Sag  | lightning     |
| 10319 | 6/11/22 21:23 | Bad Axe - Sandusky - Wilmot 3417           | Voltage Sag  | lightning     |
| 10319 | 6/11/22 21:24 | Bad Axe - Sandusky - Wilmot 3417           | Interruption | lightning     |
| 10319 | 6/15/22 20:26 | Arrowhead - Oliver 7520                    | Voltage Sag  | weather       |
| 10319 | 6/16/22 4:56  | Bad Axe - Sandusky - Wilmot 3417           | Voltage Sag  | weather       |
| 10319 | 6/16/22 5:00  | Bad Axe - Sandusky - Wilmot 3417           | Voltage Sag  | weather       |

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|       |                |                                            |              |            |
|-------|----------------|--------------------------------------------|--------------|------------|
| 10319 | 6/16/22 7:39   | Randolf - Tuscola Tie 3318                 | Voltage Sag  | weather    |
| 10319 | 6/16/22 15:52  | Derby - Tuscola Tie 9123                   | Voltage Sag  | weather    |
| 10319 | 6/16/22 20:32  | Limited Data to identify affected elements | Voltage Sag  | unknown    |
| 10319 | 6/17/22 17:47  | Limited Data to identify affected elements | Voltage Sag  | unknown    |
| 10319 | 6/17/22 17:47  | Limited Data to identify affected elements | Voltage Sag  | unknown    |
| 10319 | 6/17/22 20:20  | Limited Data to identify affected elements | Voltage Sag  | unknown    |
| 10319 | 6/18/22 16:07  | Limited Data to identify affected elements | Voltage Sag  | unknown    |
| 10319 | 6/20/22 2:44   | Limited Data to identify affected elements | Voltage Sag  | unknown    |
| 10319 | 6/20/22 14:16  | Limited Data to identify affected elements | Voltage Sag  | unknown    |
| 10319 | 7/8/22 1:08    | Jewell-Puttygut                            | Interruption | unknown    |
| 10319 | 7/13/22 12:18  | Limited Data to identify affected elements | Interruption | unknown    |
| 10319 | 7/20/22 19:14  | Sandusky - Wilmot Tie 3417                 | Interruption | weather    |
| 10319 | 7/24/22 8:41   | Tuscola - Trunk 3304                       | Voltage Sag  | unknown    |
| 10319 | 7/24/22 8:41   | Tuscola - Trunk 3304                       | Voltage Sag  | unknown    |
| 10319 | 7/26/22 5:40   | Derby Tie 9107                             | Voltage Sag  | unknown    |
| 10319 | 8/20/22 14:00  | Bad Axe - Sandusky - Wilmot 3417           | Voltage Sag  | unknown    |
| 10319 | 8/20/22 14:01  | Bad Axe - Sandusky - Wilmot 3417           | Interruption | unknown    |
| 10319 | 8/20/22 14:34  | Limited Data to identify affected elements | Voltage Sag  | unknown    |
| 10319 | 8/20/22 14:34  | Limited Data to identify affected elements | Voltage Sag  | unknown    |
| 10319 | 8/20/22 14:35  | Limited Data to identify affected elements | Interruption | unknown    |
| 10319 | 8/20/22 17:52  | Bad Axe - Sandusky - Wilmot 3417           | Interruption | unknown    |
| 10319 | 8/20/22 17:52  | Bad Axe - Sandusky - Wilmot 3417           | Voltage Sag  | unknown    |
| 10319 | 9/11/22 9:02   | Tuscola - Wilmot Tie 3323                  | Voltage Sag  | line equip |
| 10319 | 9/12/22 4:53   | Limited Data to identify affected elements | Voltage Sag  | unknown    |
| 10319 | 9/19/22 12:16  | Sandusky Tie 3417                          | Voltage Sag  | line equip |
| 10319 | 9/19/22 12:17  | Sandusky Tie 3417                          | Voltage Sag  | line equip |
| 10319 | 9/21/22 10:13  | Putnam Tie 3203                            | Voltage Sag  | unknown    |
| 10319 | 9/21/22 10:13  | Clifford Tie 3203                          | Voltage Sag  | unknown    |
| 10319 | 10/9/22 21:13  | Tuscola                                    | Voltage Sag  | unknown    |
| 10319 | 10/17/22 17:30 | Neff - Port Austin - Tie 3208              | Voltage Sag  | conductor  |
| 10319 | 10/9/22 21:13  | Tuscola                                    | Voltage Sag  | unknown    |
| 10319 | 9/26/22 07:15  | Derby- Hunters Creek Tie 9111              | Voltage Sag  | unknown    |
| 10319 | 4/1/22 09:14   | TEC Watertown                              | Interruption | unknown    |
| 10320 | 1/31/22 14:30  | Limited Data to identify affected elements | Interruption | customer   |
| 10320 | 1/31/22 15:12  | Limited Data to identify affected elements | Interruption | customer   |

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|       |               |                                            |              |               |
|-------|---------------|--------------------------------------------|--------------|---------------|
| 10320 | 3/6/22 6:48   | Limited Data to identify affected elements | Interruption | weather       |
| 10320 | 3/6/22 8:26   | Derby-Tuscola 9123                         | Interruption | weather       |
| 10320 | 3/26/22 17:56 | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10320 | 3/28/22 22:22 | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10320 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag  | weather       |
| 10320 | 3/31/22 11:39 | Port Austin - Tie 3205                     | Voltage Sag  | weather       |
| 10320 | 4/15/22 14:24 | Limited Data to identify affected elements | Voltage Sag  | weather       |
| 10320 | 4/15/22 15:18 | Bad Axe - Sandusky - Wilmot 3417           | Voltage Sag  | weather       |
| 10320 | 4/24/22 12:30 | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10320 | 5/11/22 13:56 | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10320 | 5/21/22 4:08  | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10320 | 5/23/22 11:20 | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10320 | 6/10/22 13:52 | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10320 | 6/16/22 6:25  | Limited Data to identify affected elements | Voltage Sag  | weather       |
| 10320 | 7/19/22 21:21 | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10320 | 7/20/22 15:08 | Bad Axe - Neff Tie 3402                    | Voltage Sag  | weather       |
| 10320 | 7/20/22 19:14 | Sandusky - Wilmot Tie 3417                 | Voltage Sag  | weather       |
| 10320 | 7/24/22 5:53  | Greenwood Energy - Bus 301                 | Voltage Sag  | unknown       |
| 10320 | 7/30/22 20:56 | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10320 | 9/20/22 11:02 | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10320 | 4/1/22 09:14  | TEC Delaware                               | Voltage Sag  | unknown       |
| 10321 | 4/24/22 20:54 | Colfax - Tie 6310                          | Voltage Sag  | unknown       |
| 10321 | 7/14/22 23:15 | Genoa Tie 5843                             | Voltage Sag  | line equip    |
| 10321 | 7/24/22 4:37  | Colfax - Tie 5823                          | Voltage Sag  | unknown       |
| 10321 | 8/11/22 0:51  | Genoa Tie 5843                             | Voltage Sag  | interference  |
| 10321 | 9/8/22 9:18   | Genoa Trunk 5855                           | Voltage Sag  | unknown       |
| 10321 | 10/6/22 17:49 | Genoa Trunk 5838                           | Voltage Sag  | unknown       |
| 10322 | 3/31/22 13:13 | Boyne - Trunk 7913                         | Voltage Sag  | weather       |
| 10322 | 5/20/22 2:01  | Boyne Trunk 7913                           | Voltage Sag  | unknown       |
| 10322 | 7/8/22 1:04   | Limited Data to identify affected elements | Voltage Sag  | unknown       |
| 10322 | 7/10/22 6:12  | Boyne Trunk 7909                           | Interruption | station equip |
| 10322 | 7/10/22 14:18 | Boyne Trunk 7909                           | Interruption | station equip |
| 10322 | 9/3/22 14:30  | Chesterfield Transformer 1                 | Voltage Sag  | station equip |
| 10322 | 10/5/22 11:45 | Boyne DC 8406                              | Voltage Sag  | unknown       |
| 10322 | 7/1/22 07:09  | Boyne Trunk 7909                           | Interruption | interference  |

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|       |                |                                            |              |              |
|-------|----------------|--------------------------------------------|--------------|--------------|
| 10323 | 4/3/22 15:51   | Superior                                   | Voltage Sag  | unknown      |
| 10323 | 4/14/22 17:20  | Carpenter - Superior 1568                  | Voltage Sag  | line equip   |
| 10323 | 4/28/22 0:25   | Carpenter - Superior 1568                  | Interruption | unknown      |
| 10323 | 5/27/22 3:32   | Carpenter - Superior 1568                  | Voltage Sag  | interference |
| 10323 | 6/1/22 11:59   | Saline-Pioneer Tie 7408                    | Voltage Sag  | weather      |
| 10323 | 6/3/22 14:05   | Limited Data to identify affected elements | Voltage Sag  | unknown      |
| 10323 | 7/28/22 17:16  | Superior Trunk 1502                        | Voltage Sag  | unknown      |
| 10323 | 9/10/22 11:37  | Lark - Pioneer - Saline Tie 7430           | Voltage Sag  | unknown      |
| 10324 | 2/17/22 22:40  | River Rouge - Navarre                      | Voltage Sag  | weather      |
| 10324 | 6/16/22 9:21   | Brownstown - Berlin                        | Voltage Sag  | weather      |
| 10324 | 8/30/22 16:59  | Monroe - Lallendorf                        | Voltage Sag  | line equip   |
| 10325 | 2/2/22 2:53    | Anita Generation 3                         | Voltage Sag  | customer     |
| 10325 | 6/18/22 0:57   | Baltic Trunk 8215                          | Interruption | weather      |
| 10325 | 6/19/22 14:31  | Baltic Trunk 8215                          | Voltage Sag  | weather      |
| 10326 | 2/19/22 15:17  | Argo - Superior 1531                       | Voltage Sag  | unknown      |
| 10326 | 3/1/22 7:04    | Phoenix Trunk 5510                         | Interruption | unknown      |
| 10326 | 3/1/22 7:04    | Phoenix Trunk 5510                         | Voltage Sag  | unknown      |
| 10326 | 3/1/22 7:04    | Phoenix Trunk 5510                         | Voltage Sag  | unknown      |
| 10326 | 4/3/22 15:51   | Superior                                   | Voltage Sag  | unknown      |
| 10326 | 4/3/22 15:51   | Superior                                   | Voltage Sag  | unknown      |
| 10326 | 4/14/22 18:36  | Argo - Phoenix 5517                        | Voltage Sag  | weather      |
| 10326 | 4/14/22 18:36  | Argo - Phoenix 5517                        | Voltage Sag  | weather      |
| 10326 | 4/14/22 18:36  | Argo - Phoenix 5517                        | Voltage Sag  | weather      |
| 10326 | 6/1/22 12:00   | Saline-Pioneer Tie 7408                    | Voltage Sag  | weather      |
| 10326 | 6/20/22 10:36  | Phoenix Trunk 5510                         | Voltage Sag  | unknown      |
| 10326 | 7/28/22 17:16  | Superior Trunk 1502                        | Voltage Sag  | unknown      |
| 10326 | 7/28/22 17:16  | Superior Trunk 1502                        | Voltage Sag  | unknown      |
| 10326 | 8/31/22 9:05   | Phoenix Tie 5513                           | Voltage Sag  | weather      |
| 10326 | 8/31/22 9:05   | Phoenix Tie 5513                           | Voltage Sag  | weather      |
| 10326 | 8/31/22 14:01  | Phoenix Tie 5513                           | Voltage Sag  | weather      |
| 10326 | 9/10/22 11:38  | Lark - Pioneer - Saline Tie 7430           | Voltage Sag  | unknown      |
| 10326 | 9/20/22 17:50  | Phoenix Tie 5513                           | Voltage Sag  | unknown      |
| 10326 | 9/20/22 17:50  | Phoenix Tie 5513                           | Voltage Sag  | unknown      |
| 10326 | 9/20/22 17:50  | Phoenix Tie 5513                           | Voltage Sag  | unknown      |
| 10326 | 10/10/22 10:33 | Phoenix                                    | Voltage Sag  | unknown      |
| 10326 | 10/10/22 10:34 | Phoenix                                    | Voltage Sag  | unknown      |
| 10326 | 10/10/22 10:34 | Phoenix                                    | Voltage Sag  | unknown      |
| 10326 | 10/10/22 10:34 | Phoenix                                    | Voltage Sag  | unknown      |
| 10326 | 10/10/22 10:34 | Phoenix                                    | Voltage Sag  | unknown      |
| 10326 | 10/10/22 10:34 | Phoenix                                    | Voltage Sag  | unknown      |
| 10326 | 10/10/22 10:34 | Phoenix                                    | Voltage Sag  | unknown      |
| 10326 | 10/10/22 10:34 | Phoenix                                    | Voltage Sag  | unknown      |
| 10327 | 2/17/22 22:39  | River Rouge - Navarre                      | Voltage Sag  | weather      |
| 10327 | 6/16/22 9:20   | Brownstown - Berlin                        | Voltage Sag  | weather      |
| 10327 | 8/8/22 21:11   | Navarre Trunk 385                          | Voltage Sag  | conductor    |
| 10328 | 2/17/22 22:37  | River Rouge - Navarre                      | Voltage Sag  | weather      |
| 10328 | 2/17/22 22:39  | River Rouge - Navarre                      | Voltage Sag  | weather      |
| 10328 | 2/17/22 22:40  | River Rouge - Navarre                      | Voltage Sag  | weather      |

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|       |                |                                            |              |              |
|-------|----------------|--------------------------------------------|--------------|--------------|
| 10328 | 2/17/22 22:40  | River Rouge - Navarre                      | Voltage Sag  | weather      |
| 10328 | 6/16/22 9:18   | Limited Data to identify affected elements | Voltage Sag  | unknown      |
| 10328 | 6/16/22 9:20   | Brownstown - Berlin                        | Voltage Sag  | weather      |
| 10328 | 6/16/22 9:20   | Brownstown - Berlin                        | Voltage Sag  | weather      |
| 10328 | 6/16/22 9:21   | Brownstown - Berlin                        | Voltage Sag  | weather      |
| 10328 | 7/17/22 8:19   | Ironton Trunk 3028                         | Voltage Sag  | interference |
| 10328 | 7/17/22 8:21   | Ironton Trunk 3028                         | Voltage Sag  | interference |
| 10328 | 7/17/22 8:21   | Ironton Trunk 3028                         | Voltage Sag  | interference |
| 10328 | 7/17/22 8:21   | Ironton Trunk 3028                         | Voltage Sag  | interference |
| 10329 | 2/19/22 15:17  | Argo - Superior 1531                       | Voltage Sag  | unknown      |
| 10329 | 3/1/22 7:04    | Phoenix Trunk 5510                         | Voltage Sag  | unknown      |
| 10329 | 4/3/22 15:52   | Superior                                   | Voltage Sag  | unknown      |
| 10329 | 4/14/22 18:36  | Argo - Phoenix 5517                        | Voltage Sag  | weather      |
| 10329 | 7/28/22 17:16  | Superior Trunk 1502                        | Voltage Sag  | unknown      |
| 10329 | 8/31/22 9:05   | Phoenix Tie 5513                           | Voltage Sag  | weather      |
| 10329 | 8/31/22 13:59  | Phoenix Tie 5513                           | Voltage Sag  | weather      |
| 10329 | 9/20/22 17:50  | Phoenix Tie 5513                           | Voltage Sag  | unknown      |
| 10329 | 10/10/22 10:34 | Phoenix                                    | Voltage Sag  | unknown      |
| 10329 | 10/10/22 10:34 | Phoenix                                    | Voltage Sag  | unknown      |
| 10330 | 2/2/22 0:40    | Custer Trunk 1403                          | Interruption | unknown      |
| 10330 | 2/25/22 10:54  | Custer-Trunk 1470                          | Voltage Sag  | line equip   |
| 10330 | 6/29/22 14:05  | Custer - Rockwood Tie 1423                 | Voltage Sag  | unknown      |
| 10330 | 7/16/22 17:50  | Custer - Monroe Power Plant                | Voltage Sag  | unknown      |
| 10331 | 1/5/22 9:11    | Dayton - Luzon                             | Voltage Sag  | unknown      |
| 10331 | 1/5/22 10:37   | Limited Data to identify affected elements | Voltage Sag  | unknown      |
| 10331 | 2/4/22 19:50   | Limited Data to identify affected elements | Voltage Sag  | customer     |
| 10331 | 2/17/22 22:40  | River Rouge - Navarre                      | Voltage Sag  | weather      |
| 10331 | 2/19/22 0:43   | Limited Data to identify affected elements | Voltage Sag  | customer     |
| 10331 | 2/26/22 17:11  | Limited Data to identify affected elements | Voltage Sag  | unknown      |
| 10331 | 3/31/22 8:05   | Newburgh - Peru                            | Voltage Sag  | weather      |
| 10331 | 3/31/22 8:28   | Belle River Bus 302                        | Voltage Sag  | weather      |
| 10331 | 4/3/22 15:52   | Superior                                   | Voltage Sag  | unknown      |
| 10331 | 4/14/22 17:21  | Carpenter - Superior 1568                  | Voltage Sag  | line equip   |
| 10331 | 4/14/22 21:41  | Carpenter - Superior 1568                  | Voltage Sag  | weather      |
| 10331 | 4/23/22 3:47   | Limited Data to identify affected elements | Voltage Sag  | customer     |
| 10331 | 4/26/22 16:38  | Limited Data to identify affected elements | Voltage Sag  | customer     |
| 10331 | 4/28/22 0:25   | Carpenter - Superior 1568                  | Voltage Sag  | unknown      |
| 10331 | 5/27/22 3:33   | Carpenter - Superior 1568                  | Voltage Sag  | interference |
| 10331 | 6/1/22 11:59   | Saline-Pioneer Tie 7408                    | Voltage Sag  | weather      |
| 10331 | 6/3/22 14:05   | Limited Data to identify affected elements | Voltage Sag  | unknown      |

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|       |               |                                            |             |               |
|-------|---------------|--------------------------------------------|-------------|---------------|
| 10331 | 6/9/22 14:12  | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10331 | 6/13/22 21:12 | Dayton - Luzon 1473                        | Voltage Sag | line equip    |
| 10331 | 6/14/22 1:32  | Carpenter - Luzon 3705                     | Voltage Sag | unknown       |
| 10331 | 6/16/22 9:21  | Brownstown - Berlin                        | Voltage Sag | weather       |
| 10331 | 6/24/22 23:39 | Limited Data to identify affected elements | Voltage Sag | Interference  |
| 10331 | 6/29/22 13:55 | Custer - Rockwood Tie 1423                 | Voltage Sag | unknown       |
| 10331 | 7/10/22 8:40  | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10331 | 7/14/22 9:19  | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10331 | 7/16/22 17:51 | Custer - Monroe Power Plant                | Voltage Sag | unknown       |
| 10331 | 7/24/22 7:38  | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10331 | 7/28/22 17:17 | Superior Trunk 1502                        | Voltage Sag | unknown       |
| 10331 | 7/31/22 8:26  | Monroe - Wayne                             | Voltage Sag | line equip    |
| 10331 | 8/17/22 16:44 | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10331 | 8/20/22 16:52 | Milan - Monroe Power Plant                 | Voltage Sag | weather       |
| 10331 | 8/21/22 12:39 | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10331 | 8/21/22 17:11 | Dayton - Romulus Tie 7745                  | Voltage Sag | unknown       |
| 10331 | 8/30/22 16:59 | Monroe - Lallendorf                        | Voltage Sag | line equip    |
| 10331 | 8/30/22 23:41 | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10331 | 8/31/22 9:06  | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10331 | 9/10/22 11:38 | Lark - Pioneer - Saline Tie 7430           | Voltage Sag | unknown       |
| 10331 | 9/20/22 18:04 | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10331 | 9/21/22 11:41 | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10331 | 7/6/22 14:39  | Dayton - Romulus                           | Voltage Sag | unknown       |
| 10331 | 7/6/22 15:27  | Dayton - Romulus                           | Voltage Sag | unknown       |
| 10332 | 1/7/22 12:17  | Wheeler Transformer 2                      | Voltage Sag | station equip |
| 10332 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag | weather       |
| 10332 | 7/12/22 2:15  | Limited Data to identify affected elements | Voltage Sag | unknown       |
| 10332 | 10/3/22 08:23 | Redrun Trunk 3646                          | Voltage Sag | unknown       |
| 10332 | 10/3/22 08:49 | Redrun Trunk 3646                          | Voltage Sag | unknown       |
| 10332 | 7/2/22 05:35  | Redrun Trunk 3646                          | Voltage Sag | unknown       |
| 10333 | 1/6/22 1:54   | Erin - Stephens                            | Voltage Sag | station equip |
| 10333 | 1/7/22 12:17  | Wheeler Transformer 2                      | Voltage Sag | station equip |
| 10333 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag | weather       |
| 10333 | 3/31/22 8:27  | Belle River Bus 302                        | Voltage Sag | weather       |
| 10333 | 4/11/22 15:05 | Limited Data to identify affected elements | Voltage Sag | customer      |
| 10333 | 6/3/22 20:05  | Pontiac-Placid                             | Voltage Sag | station equip |

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|       |               |                             |              |               |
|-------|---------------|-----------------------------|--------------|---------------|
| 10333 | 6/3/22 20:22  | Pontiac-Placid              | Voltage Sag  | station equip |
| 10333 | 7/8/22 1:07   | Jewell-Puttygut             | Voltage Sag  | unknown       |
| 10333 | 10/5/22 11:47 | Jewell - Stephens           | Interruption | Interference  |
| 10333 | 10/5/22 11:48 | Jewell - Stephens           | Voltage Sag  | Interference  |
| 10333 | 4/1/22 09:14  | Lindsey 1                   | Voltage Sag  | unknown       |
| 10334 | 3/31/22 8:27  | Belle River Bus 302         | Voltage Sag  | weather       |
| 10334 | 5/21/22 10:17 | Chesterfield DC 8453        | Voltage Sag  | line equip    |
| 10334 | 7/8/22 1:07   | Jewell-Puttygut             | Voltage Sag  | unknown       |
| 10334 | 8/29/22 18:30 | Victor - Tie 4911           | Voltage Sag  | weather       |
| 10334 | 9/19/22 6:15  | Victor Tie 810              | Voltage Sag  | unknown       |
| 10334 | 4/1/22 09:14  | Cotton 1                    | Voltage Sag  | unknown       |
| 10335 | 1/30/22 3:27  | Evergreen Trunk 2250        | Voltage Sag  | conductor     |
| 10335 | 4/13/22 12:38 | Evergreen Trunk 2218        | Voltage Sag  | unknown       |
| 10335 | 4/13/22 13:17 | Evergreen Trunk 2218        | Voltage Sag  | unknown       |
| 10335 | 5/17/22 9:13  | Evergreen Transformer 3     | Voltage Sag  | station equip |
| 10335 | 7/15/22 19:21 | River Rouge - Warren 2      | Voltage Sag  | Interference  |
| 10335 | 7/24/22 22:18 | Evergreen Trunk 2247        | Voltage Sag  | unknown       |
| 10335 | 7/25/22 12:25 | Evergreen Trunk 2247        | Voltage Sag  | unknown       |
| 10335 | 7/30/22 3:41  | Evergreen Trunk 2233        | Voltage Sag  | conductor     |
| 10336 | 3/31/22 8:05  | Newburgh - Peru             | Voltage Sag  | weather       |
| 10336 | 6/16/22 9:21  | Brownstown - Berlin         | Voltage Sag  | weather       |
| 10336 | 8/30/22 16:59 | Monroe - Lallendorf         | Voltage Sag  | line equip    |
| 10337 | 7/16/22 17:50 | Custer - Monroe Power Plant | Voltage Sag  | unknown       |
| 10337 | 8/20/22 16:51 | Milan - Monroe Power Plant  | Voltage Sag  | weather       |
| 10338 | 3/31/22 8:27  | Belle River Bus 302         | Voltage Sag  | weather       |



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A number of outages for the circuits in Appendix 1A were recorded by AMI meters but could not be associated with an InService OMS event using current algorithms. As a result, no cause can be directly attributed to these events. These unassociated AMI meter outages account for 5.8% of the customers interrupted and 5.9% of the customer-minutes interrupted for these circuits.

**Appendix 1A**  
**Outage and Cause Listing - SAIFI - System Basis**

| Ref# | Metric | Rank | Circuit   | MED | Storm | Interruption Date/Time | Customers Interrupted | Customer Minutes Interrupted | Cause              |
|------|--------|------|-----------|-----|-------|------------------------|-----------------------|------------------------------|--------------------|
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 01/17/22 10:45         | 252                   | 16,158                       | Tree               |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 01/25/22 13:32         | 5                     | 185                          | Animal             |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 02/11/22 09:58         | 1                     | 10                           | Equipment          |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 02/15/22 09:31         | 1                     | 13                           | AMI - No Job/Cause |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 03/02/22 14:15         | 6                     | 544                          | Animal             |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 03/06/22 09:11         | 1                     | 5                            | Wind               |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 03/06/22 09:11         | 1                     | 5                            | Wind               |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 03/06/22 09:11         | 1,403                 | 7,547                        | Tree               |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 03/06/22 09:11         | 65                    | 350                          | Other              |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 03/06/22 09:12         | 62                    | 334                          | Other              |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 03/06/22 09:12         | 1                     | 5                            | Wind               |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 03/06/22 09:12         | 3                     | 16                           | Wind               |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 03/06/22 09:12         | 23                    | 124                          | Other              |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 03/06/22 09:12         | 2                     | 11                           | Wind               |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 03/06/22 09:12         | 1                     | 5                            | Wind               |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 03/06/22 09:12         | 1                     | 5                            | Wind               |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 03/06/22 09:12         | 515                   | 2,770                        | AMI - No Job/Cause |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 03/06/22 09:12         | 37                    | 199                          | Other              |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 03/06/22 09:12         | 1                     | 5                            | Wind               |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 03/06/22 09:12         | 2                     | 11                           | Wind               |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 03/06/22 09:12         | 60                    | 323                          | Other              |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 03/06/22 09:12         | 1                     | 5                            | Wind               |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 03/06/22 09:12         | 1                     | 5                            | Wind               |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 03/06/22 09:12         | 779                   | 5,028                        | Wind               |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 03/06/22 10:16         | 2                     | 1,661                        | AMI - No Job/Cause |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 03/17/22 17:59         | 7                     | 898                          | Equipment          |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 04/12/22 07:25         | 1                     | 180                          | Animal             |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 04/13/22 17:24         | 1                     | 446                          | Equipment          |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 04/27/22 16:36         | 1                     | 46                           | AMI - No Job/Cause |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 04/27/22 17:43         | 8                     | 373                          | AMI - No Job/Cause |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 04/28/22 11:40         | 1                     | 196                          | AMI - No Job/Cause |
| 1A1  | SAIFI  | 1    | FISHR8188 | -   |       | 05/01/22 03:11         | 3                     | 72                           | AMI - No Job/Cause |

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|-----|-------|---|-----------|-----|-------|----------------|-------|---------|--------------------|
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 05/01/22 08:28 | 54    | 6,623   | Equipment          |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 05/02/22 08:50 | 1     | 225     | AMI - No Job/Cause |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 05/05/22 19:45 | 1     | 75      | AMI - No Job/Cause |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 05/05/22 19:45 | 17    | 1,273   | Other              |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 05/07/22 12:42 | 56    | 6,061   | Animal             |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 05/07/22 12:42 | 2     | 216     | AMI - No Job/Cause |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 05/15/22 15:11 | 358   | 127,191 | Animal             |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 05/15/22 15:12 | 2     | 707     | Equipment          |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 05/15/22 15:12 | 274   | 97,030  | AMI - No Job/Cause |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 05/15/22 15:13 | 1     | 354     | Equipment          |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 05/15/22 17:11 | 1     | 184     | Equipment          |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 05/15/22 17:11 | 141   | 25,877  | Animal             |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 05/15/22 17:11 | 5     | 918     | Equipment          |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 05/19/22 07:09 | 3     | 485     | Equipment          |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 05/20/22 01:03 | 149   | 3,497   | Intentional        |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 05/20/22 01:03 | 1,839 | 43,232  | Intentional        |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 05/20/22 01:03 | 850   | 19,960  | Intentional        |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 05/20/22 13:05 | 9     | 2,284   | Unknown            |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 05/20/22 13:06 | 2     | 507     | Tree               |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 05/20/22 15:39 | 383   | 38,750  | Loading            |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 05/20/22 16:17 | 2,447 | 154,727 | Other              |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 05/22/22 20:42 | 1     | 7       | Unknown            |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 06/06/22 09:35 | 1     | 560     | Tree               |
| 1A1 | SAIFI | 1 | FISHR8188 | -   | Small | 06/18/22 01:55 | 1     | 437     | Tree               |
| 1A1 | SAIFI | 1 | FISHR8188 | -   | Small | 06/18/22 01:55 | 7     | 3,059   | Wind               |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 06/21/22 18:09 | 3     | 170     | Animal             |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 06/21/22 18:09 | 3     | 170     | AMI - No Job/Cause |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 06/25/22 11:04 | 8     | 300     | Animal             |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 06/29/22 12:32 | 1     | 79      | Animal             |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 06/29/22 12:32 | 16    | 1,263   | Animal             |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 07/02/22 12:40 | 78    | 2,227   | Unknown            |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 07/06/22 11:16 | 1     | 11      | Equipment          |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 07/06/22 12:49 | 2,849 | 497,136 | Equipment          |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 07/06/22 12:49 | 260   | 45,337  | Other              |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 07/06/22 21:12 | 1     | 6       | AMI - No Job/Cause |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 07/06/22 23:17 | 6     | 311     | AMI - No Job/Cause |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 07/07/22 14:42 | 2     | 156     | Animal             |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 07/09/22 02:54 | 10    | 509     | Animal             |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 07/14/22 17:54 | 1     | 40      | Unknown            |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 07/14/22 17:54 | 1     | 43      | Unknown            |
| 1A1 | SAIFI | 1 | FISHR8188 | MED |       | 08/03/22 11:38 | 26    | 1,705   | Animal             |
| 1A1 | SAIFI | 1 | FISHR8188 | MED |       | 08/03/22 11:38 | 1     | 66      | AMI - No Job/Cause |
| 1A1 | SAIFI | 1 | FISHR8188 | MED | Small | 08/03/22 19:23 | 37    | 7,955   | Tree               |

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|-----|-------|---|-----------|-----|-------|----------------|-------|---------|---------------------|
| 1A1 | SAIFI | 1 | FISHR8188 | MED | Small | 08/03/22 19:23 | 2     | 430     | AMI - No Job/Cause  |
| 1A1 | SAIFI | 1 | FISHR8188 | -   | Small | 08/04/22 18:57 | 2     | 15      | AMI - No Job/Cause  |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 08/08/22 01:13 | 7     | 715     | AMI - No Job/Cause  |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 08/08/22 01:13 | 1     | 102     | Equipment           |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 08/10/22 07:11 | 11    | 568     | Equipment           |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 08/12/22 16:17 | 1     | 18      | Equipment           |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 08/15/22 07:59 | 1     | 73      | Tree                |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 08/23/22 10:08 | 11    | 543     | Unknown             |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 08/24/22 11:30 | 7     | 230     | Unknown             |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 08/24/22 15:11 | 19    | 2,156   | Equipment           |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 08/24/22 15:11 | 8     | 3,657   | Public Interference |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 08/26/22 10:59 | 9     | 689     | Equipment           |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 08/26/22 11:02 | 14    | 368     | Equipment           |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 08/26/22 12:43 | 9     | 309     | Animal              |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 08/26/22 14:01 | 7     | 65      | AMI - No Job/Cause  |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 08/28/22 07:55 | 1     | 259     | AMI - No Job/Cause  |
| 1A1 | SAIFI | 1 | FISHR8188 | MED | Cat   | 08/30/22 10:16 | 9     | 28,076  | Wind                |
| 1A1 | SAIFI | 1 | FISHR8188 | -   | Cat   | 08/31/22 19:07 | 1     | 2,368   | Wind                |
| 1A1 | SAIFI | 1 | FISHR8188 | -   | Cat   | 08/31/22 19:07 | 1     | 2,368   | Tree                |
| 1A1 | SAIFI | 1 | FISHR8188 | -   | Cat   | 09/01/22 14:56 | 15    | 2,025   | Animal              |
| 1A1 | SAIFI | 1 | FISHR8188 | -   | Cat   | 09/03/22 18:54 | 1     | 6       | AMI - No Job/Cause  |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 09/06/22 11:56 | 1     | 9       | AMI - No Job/Cause  |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 09/10/22 21:20 | 1     | 36      | Equipment           |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 09/13/22 20:22 | 12    | 5,714   | Equipment           |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 09/21/22 09:37 | 13    | 2,107   | Lightning           |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 09/21/22 09:37 | 8     | 1,297   | Lightning           |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 09/21/22 09:37 | 9     | 1,459   | Lightning           |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 09/21/22 10:01 | 3     | 508     | Lightning           |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 09/21/22 10:01 | 26    | 4,207   | AMI - No Job/Cause  |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 09/21/22 10:01 | 15    | 2,614   | Unknown             |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 09/21/22 10:01 | 8     | 1,083   | Equipment           |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 09/30/22 17:20 | 9     | 612     | Animal              |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 10/05/22 17:31 | 1     | 7       | Unknown             |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 10/09/22 08:18 | 4     | 168     | Animal              |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 10/11/22 08:08 | 13    | 1,240   | Animal              |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 10/15/22 08:54 | 2,844 | 131,930 | Equipment           |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 10/15/22 08:55 | 83    | 3,839   | Equipment           |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 10/15/22 08:55 | 169   | 7,813   | AMI - No Job/Cause  |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 10/18/22 00:22 | 1     | 14      | Equipment           |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 10/20/22 09:27 | 3     | 163     | Animal              |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 10/20/22 09:27 | 4     | 215     | Other               |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 10/27/22 08:49 | 4     | 251     | Animal              |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 10/27/22 09:07 | 1     | 60      | AMI - No Job/Cause  |

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|-----|-------|---|-----------|-----|-------|----------------|----|-------|--------------------|
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 10/27/22 09:07 | 4  | 238   | Animal             |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 10/31/22 18:51 | 1  | 8     | Unknown            |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 11/01/22 09:01 | 3  | 192   | Animal             |
| 1A1 | SAIFI | 1 | FISHR8188 | MED | Small | 11/06/22 09:11 | 1  | 90    | Wind               |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 11/12/22 07:59 | 2  | 94    | Equipment          |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 11/12/22 07:59 | 4  | 188   | Equipment          |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 12/15/22 09:31 | 1  | 47    | AMI - No Job/Cause |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 12/16/22 17:01 | 1  | 8     | AMI - No Job/Cause |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 12/22/22 11:11 | 1  | 41    | AMI - No Job/Cause |
| 1A1 | SAIFI | 1 | FISHR8188 | -   | Small | 12/23/22 09:53 | 38 | 5,327 | Tree               |
| 1A1 | SAIFI | 1 | FISHR8188 | -   | Small | 12/23/22 09:53 | 1  | 140   | AMI - No Job/Cause |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 12/30/22 20:27 | 1  | 64    | Unknown            |
| 1A1 | SAIFI | 1 | FISHR8188 | -   |       | 12/30/22 20:28 | 1  | 64    | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 01/04/22 12:55 | 1  | 27    | Intentional        |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 01/09/22 13:06 | 1  | 244   | Equipment          |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 01/14/22 15:13 | 1  | 12    | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 02/05/22 20:09 | 2  | 105   | Tree               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 02/07/22 21:27 | 1  | 6     | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 02/21/22 13:34 | 7  | 112   | Intentional        |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 03/04/22 10:36 | 1  | 6     | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 03/28/22 16:26 | 1  | 973   | Equipment          |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   | Small | 03/31/22 05:56 | 3  | 1,999 | Wind               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   | Small | 03/31/22 05:56 | 1  | 666   | Wind               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   | Small | 03/31/22 05:56 | 2  | 1,333 | Wind               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   | Small | 03/31/22 05:56 | 3  | 1,999 | Wind               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   | Small | 03/31/22 05:56 | 1  | 666   | Wind               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   | Small | 03/31/22 05:56 | 3  | 1,999 | Wind               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   | Small | 03/31/22 05:56 | 2  | 1,333 | Wind               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   | Small | 03/31/22 05:56 | 5  | 3,332 | Wind               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   | Small | 03/31/22 05:56 | 4  | 2,665 | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   | Small | 03/31/22 05:56 | 6  | 3,998 | Wind               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   | Small | 03/31/22 08:57 | 1  | 198   | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   | Small | 03/31/22 11:17 | 4  | 5,904 | Wind               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   | Small | 03/31/22 13:20 | 1  | 202   | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 04/05/22 08:42 | 1  | 95    | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   | Small | 04/14/22 15:43 | 1  | 47    | Wind               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 04/16/22 23:05 | 1  | 6     | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 04/17/22 08:48 | 1  | 5     | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 04/17/22 11:59 | 1  | 2,092 | Equipment          |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 04/22/22 14:46 | 1  | 230   | Equipment          |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 04/23/22 09:52 | 2  | 307   | Equipment          |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 04/27/22 16:32 | 1  | 109   | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 04/28/22 10:46 | 1  | 222   | AMI - No Job/Cause |

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|-----|-------|---|-----------|-----|-------|----------------|-------|---------|--------------------|
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 05/04/22 14:31 | 1     | 10      | Other              |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 05/05/22 18:31 | 1     | 6       | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 05/05/22 18:40 | 1     | 6       | Tree               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 05/12/22 06:52 | 1     | 5       | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 05/12/22 19:09 | 1     | 42      | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 05/12/22 19:10 | 2,235 | 125,921 | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 05/12/22 19:10 | 1     | 60      | Other              |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 05/12/22 19:10 | 5     | 299     | Equipment          |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 05/12/22 19:10 | 1     | 48      | Other              |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 05/12/22 19:10 | 1     | 59      | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 05/15/22 19:11 | 1     | 5       | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 05/18/22 09:12 | 1     | 8       | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 05/19/22 21:46 | 1     | 6       | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 05/22/22 18:58 | 1     | 25      | Tree               |
| 1A2 | SAIFI | 2 | DUBLN8205 | MED | Small | 06/01/22 12:26 | 27    | 12,400  | Tree               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 06/04/22 09:28 | 66    | 6,135   | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 06/08/22 14:10 | 1     | 18      | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 06/08/22 14:11 | 1,143 | 22,963  | Animal             |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 06/08/22 14:11 | 4     | 82      | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 06/13/22 23:43 | 2     | 422     | Lightning          |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 06/14/22 10:02 | 1     | 5       | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 06/15/22 11:51 | 3,209 | 135,436 | Tree               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 06/15/22 11:51 | 1     | 41      | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 06/20/22 13:34 | 21    | 912     | Tree               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 06/21/22 07:33 | 66    | 4,021   | Animal             |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 06/21/22 19:32 | 1     | 305     | Equipment          |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 06/22/22 19:27 | 1     | 347     | Equipment          |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 06/23/22 06:43 | 66    | 6,930   | Equipment          |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 06/23/22 09:37 | 2     | 180     | Animal             |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 06/25/22 08:21 | 1     | 5       | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 06/26/22 08:22 | 2     | 890     | Tree               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 07/02/22 07:04 | 66    | 6,573   | Equipment          |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 07/09/22 08:32 | 66    | 5,698   | Ice                |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 07/12/22 06:42 | 13    | 1,828   | Equipment          |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 07/12/22 06:42 | 45    | 6,327   | Other              |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 07/12/22 06:42 | 2     | 146     | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 07/12/22 06:42 | 1     | 141     | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 07/12/22 19:32 | 5     | 412     | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 07/14/22 09:27 | 1     | 16      | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   | Small | 07/21/22 19:13 | 102   | 86,636  | Tree               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 07/24/22 00:59 | 8     | 5,062   | Tree               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 07/24/22 00:59 | 4     | 2,530   | Tree               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 07/25/22 18:01 | 6     | 327     | Tree               |

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|-----|-------|---|-----------|-----|-------|----------------|-----|---------|--------------------|
| 1A2 | SAIFI | 2 | DUBLN8205 | MED | Small | 08/04/22 00:18 | 1   | 1,167   | Wind               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   | Small | 08/04/22 23:06 | 28  | 22,259  | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   | Small | 08/04/22 23:06 | 155 | 125,306 | Equipment          |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   | Small | 08/04/22 23:06 | 14  | 11,780  | Tree               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 08/09/22 04:17 | 12  | 3,062   | Animal             |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 08/12/22 11:55 | 5   | 310     | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 08/17/22 15:36 | 1   | 67      | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 08/17/22 15:36 | 839 | 62,489  | Wind               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 08/28/22 17:35 | 3   | 16      | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | MED | Cat   | 08/29/22 18:07 | 1   | 1,400   | Tree               |
| 1A2 | SAIFI | 2 | DUBLN8205 | MED | Cat   | 08/29/22 18:07 | 2   | 5,370   | Other              |
| 1A2 | SAIFI | 2 | DUBLN8205 | MED | Cat   | 08/29/22 18:07 | 1   | 1,398   | Wind               |
| 1A2 | SAIFI | 2 | DUBLN8205 | MED | Cat   | 08/29/22 18:07 | 1   | 1,399   | Wind               |
| 1A2 | SAIFI | 2 | DUBLN8205 | MED | Cat   | 08/29/22 18:07 | 162 | 435,326 | Tree               |
| 1A2 | SAIFI | 2 | DUBLN8205 | MED | Cat   | 08/29/22 18:07 | 3   | 8,055   | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | MED | Cat   | 08/29/22 18:07 | 1   | 2,685   | Wind               |
| 1A2 | SAIFI | 2 | DUBLN8205 | MED | Cat   | 08/29/22 18:07 | 2   | 5,408   | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | MED | Cat   | 08/29/22 18:07 | 1   | 2,685   | Wind               |
| 1A2 | SAIFI | 2 | DUBLN8205 | MED | Cat   | 08/29/22 19:18 | 722 | 935,630 | Wind               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   | Cat   | 09/03/22 09:28 | 8   | 6,022   | Tree               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   | Cat   | 09/04/22 13:36 | 1   | 11      | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 09/06/22 19:35 | 1   | 979     | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 09/12/22 14:37 | 1   | 156     | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 09/12/22 15:17 | 1   | 9       | Tree               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 09/18/22 00:29 | 2   | 69      | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 09/19/22 00:46 | 2   | 116     | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 09/20/22 18:47 | 1   | 1,077   | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 09/21/22 15:01 | 1   | 385     | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 09/22/22 17:16 | 1   | 733     | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 09/24/22 08:09 | 1   | 1,753   | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 09/26/22 13:43 | 1   | 434     | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 09/29/22 13:46 | 1   | 7       | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 10/01/22 08:50 | 152 | 20,462  | Equipment          |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 10/20/22 13:25 | 46  | 4,619   | Tree               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 10/26/22 05:32 | 1   | 5       | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 10/29/22 10:19 | 1   | 9       | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 10/29/22 10:20 | 2   | 18      | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 11/01/22 16:07 | 1   | 6       | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 11/02/22 10:05 | 37  | 3,400   | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 11/02/22 12:03 | 8   | 462     | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 11/02/22 12:33 | 1   | 8       | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 11/02/22 12:33 | 2   | 16      | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 11/03/22 11:53 | 1   | 74      | AMI - No Job/Cause |

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|     |       |   |           |     |       |                |       |         |                    |
|-----|-------|---|-----------|-----|-------|----------------|-------|---------|--------------------|
| 1A2 | SAIFI | 2 | DUBLN8205 | MED | Small | 11/05/22 11:02 | 3,202 | 73,632  | Equipment          |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 11/08/22 13:14 | 12    | 927     | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 11/10/22 14:39 | 1     | 190     | Other              |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 11/14/22 13:57 | 1     | 34      | Tree               |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 11/17/22 12:12 | 3     | 172     | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 11/19/22 11:45 | 6     | 358     | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 11/20/22 10:28 | 1     | 174     | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 11/20/22 10:29 | 10    | 1,744   | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 11/20/22 10:29 | 16    | 918     | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 11/20/22 10:51 | 4     | 488     | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 11/29/22 09:48 | 2     | 32      | AMI - No Job/Cause |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 12/08/22 09:01 | 74    | 7,233   | Unknown            |
| 1A2 | SAIFI | 2 | DUBLN8205 | -   |       | 12/08/22 11:05 | 124   | 16,187  | Unknown            |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 02/05/22 11:12 | 1     | 126     | Other              |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 02/05/22 11:12 | 1,276 | 154,579 | Equipment          |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 02/07/22 11:33 | 1     | 29      | AMI - No Job/Cause |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 02/07/22 23:56 | 1     | 17      | AMI - No Job/Cause |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 02/08/22 09:06 | 1     | 145     | AMI - No Job/Cause |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 02/08/22 17:07 | 1     | 11      | Equipment          |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 02/09/22 12:34 | 3     | 189     | AMI - No Job/Cause |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 02/10/22 13:08 | 2     | 107     | AMI - No Job/Cause |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 02/15/22 11:34 | 4     | 288     | AMI - No Job/Cause |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 02/16/22 11:31 | 1     | 66      | Intentional        |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 03/03/22 21:47 | 1     | 65      | Unknown            |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 03/03/22 21:47 | 1,249 | 81,592  | Unknown            |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 03/03/22 22:11 | 291   | 11,732  | Equipment          |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 03/05/22 10:59 | 1     | 25      | Unknown            |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 03/27/22 14:42 | 1,376 | 216,997 | Equipment          |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   | Small | 03/31/22 13:12 | 1,985 | 239,334 | Tree               |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 04/03/22 10:39 | 1     | 9       | Unknown            |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 04/05/22 10:57 | 1     | 139     | AMI - No Job/Cause |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 05/12/22 08:10 | 1     | 124     | AMI - No Job/Cause |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 05/16/22 17:08 | 1     | 19      | Equipment          |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 05/27/22 13:17 | 1,505 | 45,325  | Equipment          |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 06/10/22 09:12 | 4     | 258     | AMI - No Job/Cause |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 06/10/22 09:12 | 123   | 7,935   | Unknown            |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 06/11/22 08:25 | 10    | 1,235   | Unknown            |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   | Small | 06/17/22 23:14 | 1     | 2,477   | Tree               |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 06/20/22 16:54 | 1,355 | 302,720 | Tree               |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 06/20/22 16:54 | 1     | 223     | AMI - No Job/Cause |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 06/21/22 13:00 | 24    | 123     | Intentional        |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 06/28/22 07:13 | 2     | 219     | Animal             |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |       | 06/29/22 12:27 | 2     | 174     | Animal             |

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|-----|-------|---|-----------|-----|-----|----------------|-------|---------|---------------------|
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |     | 07/07/22 00:05 | 1     | 10      | Equipment           |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |     | 07/09/22 17:01 | 1     | 169     | Equipment           |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |     | 07/16/22 07:20 | 10    | 1,028   | Equipment           |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |     | 07/24/22 17:35 | 24    | 1,957   | Wind                |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |     | 07/25/22 12:53 | 4     | 158     | Unknown             |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |     | 08/16/22 10:25 | 1     | 410     | Animal              |
| 1A3 | SAIFI | 3 | BUNRT8426 | MED | Cat | 08/29/22 18:26 | 1     | 1,380   | Unknown             |
| 1A3 | SAIFI | 3 | BUNRT8426 | MED | Cat | 08/29/22 21:56 | 361   | 231,860 | Wind                |
| 1A3 | SAIFI | 3 | BUNRT8426 | MED | Cat | 08/29/22 22:45 | 7     | 4,225   | Other               |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   | Cat | 09/01/22 13:34 | 120   | 38,302  | Equipment           |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   | Cat | 09/01/22 13:34 | 1,423 | 358,946 | Other               |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   | Cat | 09/01/22 13:34 | 1     | 319     | Unknown             |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |     | 09/08/22 18:58 | 56    | 11,346  | Equipment           |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |     | 09/20/22 01:55 | 1     | 151     | Other               |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |     | 09/20/22 01:55 | 1     | 151     | Other               |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |     | 09/20/22 01:55 | 277   | 41,801  | Unknown             |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |     | 09/20/22 02:56 | 1,278 | 114,874 | Equipment           |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |     | 10/02/22 10:07 | 1     | 7       | Tree                |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |     | 10/06/22 22:36 | 1     | 614     | Tree                |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |     | 10/14/22 09:51 | 10    | 524     | Animal              |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |     | 10/18/22 11:21 | 3     | 68      | Intentional         |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |     | 10/20/22 14:46 | 1     | 20      | Unknown             |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |     | 10/20/22 19:59 | 25    | 979     | Other Utility       |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |     | 10/22/22 17:26 | 1     | 13      | Unknown             |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |     | 10/26/22 05:19 | 1     | 356     | Public Interference |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |     | 10/28/22 13:41 | 10    | 335     | Animal              |
| 1A3 | SAIFI | 3 | BUNRT8426 | -   |     | 11/09/22 08:06 | 1     | 161     | AMI - No Job/Cause  |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |     | 01/07/22 21:15 | 6     | 906     | Other               |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |     | 01/07/22 21:15 | 10    | 1,509   | Equipment           |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |     | 01/14/22 08:37 | 1     | 82      | Other               |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |     | 02/01/22 12:02 | 1     | 171     | Equipment           |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |     | 02/01/22 12:02 | 1     | 171     | Equipment           |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |     | 02/02/22 11:32 | 1     | 17      | Other               |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |     | 02/20/22 22:33 | 26    | 4,618   | Equipment           |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |     | 02/20/22 22:33 | 2     | 426     | AMI - No Job/Cause  |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |     | 03/18/22 01:40 | 1     | 381     | Equipment           |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |     | 03/23/22 09:42 | 47    | 3,459   | Equipment           |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |     | 03/23/22 12:51 | 13    | 1,095   | Animal              |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |     | 03/27/22 16:49 | 1     | 5       | AMI - No Job/Cause  |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |     | 03/27/22 19:07 | 1     | 5       | AMI - No Job/Cause  |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |     | 04/08/22 10:01 | 1     | 13      | Intentional         |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |     | 04/08/22 10:01 | 1     | 13      | Intentional         |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |     | 04/08/22 10:01 | 74    | 943     | AMI - No Job/Cause  |



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|-----|-------|---|-----------|-----|-------|----------------|-------|---------|--------------------|
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 04/08/22 10:01 | 1     | 13      | Intentional        |
| 1A4 | SAIFI | 4 | SWANC9408 | -   | Small | 04/14/22 14:37 | 1     | 16      | Wind               |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 04/19/22 11:13 | 11    | 1,691   | Intentional        |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 04/21/22 11:40 | 2     | 247     | Intentional        |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 04/23/22 08:43 | 1     | 13      | AMI - No Job/Cause |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 05/03/22 15:36 | 1     | 42      | Other              |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 05/03/22 15:36 | 27    | 1,303   | Equipment          |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 05/12/22 22:52 | 1     | 560     | AMI - No Job/Cause |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 05/14/22 09:36 | 6     | 396     | Other              |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 05/14/22 09:36 | 2,784 | 183,173 | Unknown            |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 05/14/22 09:37 | 13    | 855     | AMI - No Job/Cause |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 05/14/22 13:09 | 2,750 | 241,248 | Loading            |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 05/14/22 13:09 | 17    | 1,492   | AMI - No Job/Cause |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 05/14/22 13:09 | 1     | 88      | Loading            |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 05/18/22 21:07 | 1     | 131     | AMI - No Job/Cause |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 05/19/22 18:02 | 2,665 | 100,587 | Equipment          |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 05/19/22 18:02 | 15    | 566     | AMI - No Job/Cause |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 05/23/22 19:28 | 24    | 230     | AMI - No Job/Cause |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 05/24/22 23:51 | 1     | 666     | Unknown            |
| 1A4 | SAIFI | 4 | SWANC9408 | MED | Small | 06/02/22 07:26 | 1     | 296     | AMI - No Job/Cause |
| 1A4 | SAIFI | 4 | SWANC9408 | -   | Small | 06/03/22 09:23 | 1     | 420     | AMI - No Job/Cause |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 06/09/22 10:13 | 5     | 997     | Intentional        |
| 1A4 | SAIFI | 4 | SWANC9408 | -   | Small | 06/17/22 10:04 | 1     | 114     | Animal             |
| 1A4 | SAIFI | 4 | SWANC9408 | -   | Small | 06/17/22 13:21 | 1     | 6       | AMI - No Job/Cause |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 06/24/22 18:03 | 1     | 69      | AMI - No Job/Cause |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 06/24/22 18:03 | 1     | 69      | Animal             |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 06/29/22 14:04 | 1     | 49      | AMI - No Job/Cause |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 07/06/22 04:36 | 78    | 14,249  | Tree               |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 07/11/22 07:59 | 12    | 341     | Animal             |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 07/14/22 13:08 | 1     | 14      | Unknown            |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 08/02/22 12:49 | 1     | 23      | AMI - No Job/Cause |
| 1A4 | SAIFI | 4 | SWANC9408 | MED | Small | 08/04/22 11:13 | 1     | 102     | AMI - No Job/Cause |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 08/17/22 11:01 | 10    | 471     | Other              |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 08/17/22 11:01 | 86    | 4,052   | Tree               |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 08/19/22 07:53 | 1     | 122     | AMI - No Job/Cause |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 09/13/22 18:22 | 14    | 848     | Equipment          |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 09/15/22 23:48 | 1     | 6       | AMI - No Job/Cause |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 09/18/22 08:22 | 8     | 521     | Equipment          |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 09/27/22 12:17 | 1     | 92      | Animal             |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 10/04/22 05:46 | 12    | 1,717   | AMI - No Job/Cause |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 10/04/22 05:52 | 874   | 108,447 | Tree               |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 10/04/22 09:26 | 930   | 38,690  | Tree               |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 10/04/22 09:33 | 7     | 255     | AMI - No Job/Cause |

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|-----|-------|---|-----------|-----|-------|----------------|-------|---------|---------------------|
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 10/05/22 11:45 | 3     | 182     | AMI - No Job/Cause  |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 10/08/22 20:32 | 1     | 53      | Equipment           |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 10/19/22 11:22 | 37    | 3,999   | Animal              |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 10/26/22 13:28 | 2     | 17      | AMI - No Job/Cause  |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 10/26/22 13:28 | 1     | 8       | Unknown             |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 10/30/22 15:45 | 3     | 113     | Animal              |
| 1A4 | SAIFI | 4 | SWANC9408 | MED | Small | 11/05/22 20:35 | 2,043 | 128,057 | Wind                |
| 1A4 | SAIFI | 4 | SWANC9408 | MED | Small | 11/05/22 20:35 | 5     | 314     | AMI - No Job/Cause  |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 12/10/22 08:39 | 1     | 140     | AMI - No Job/Cause  |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 12/10/22 08:39 | 1     | 140     | Animal              |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 12/27/22 07:00 | 1     | 19      | AMI - No Job/Cause  |
| 1A4 | SAIFI | 4 | SWANC9408 | -   |       | 12/27/22 19:46 | 1     | 10      | AMI - No Job/Cause  |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 01/04/22 10:43 | 91    | 4,081   | Tree                |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 01/18/22 12:19 | 7     | 903     | Tree                |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 01/18/22 12:19 | 1     | 129     | Equipment           |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 02/02/22 09:13 | 124   | 11,027  | Equipment           |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 02/08/22 20:42 | 1     | 39      | AMI - No Job/Cause  |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 02/09/22 10:53 | 3     | 309     | Animal              |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 02/09/22 10:53 | 3     | 309     | Animal              |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 02/09/22 10:53 | 86    | 8,858   | Equipment           |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 02/09/22 10:53 | 1     | 103     | Other               |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 02/18/22 10:49 | 1     | 27      | AMI - No Job/Cause  |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 02/21/22 08:36 | 1     | 35      | AMI - No Job/Cause  |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 02/23/22 04:57 | 40    | 11,716  | Public Interference |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 02/23/22 04:57 | 39    | 2,777   | Public Interference |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 02/23/22 11:19 | 39    | 2,772   | Equipment           |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 03/21/22 16:28 | 1     | 85      | AMI - No Job/Cause  |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 03/29/22 12:19 | 9     | 535     | Equipment           |
| 1A5 | SAIFI | 5 | MACMB8521 | -   | Small | 03/31/22 10:04 | 40    | 22,957  | Tree                |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 04/06/22 15:59 | 30    | 5,715   | Tree                |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 04/08/22 16:46 | 1     | 57      | AMI - No Job/Cause  |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 04/11/22 06:16 | 3     | 773     | Equipment           |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 04/11/22 06:16 | 2     | 516     | AMI - No Job/Cause  |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 04/11/22 13:44 | 1     | 95      | AMI - No Job/Cause  |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 04/28/22 09:16 | 1     | 66      | Animal              |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 04/28/22 09:16 | 1     | 66      | AMI - No Job/Cause  |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 05/06/22 03:37 | 1     | 5       | AMI - No Job/Cause  |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 05/16/22 13:46 | 2,940 | 264,763 | Equipment           |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 05/16/22 13:46 | 1     | 59      | Unknown             |
| 1A5 | SAIFI | 5 | MACMB8521 | -   | Small | 05/21/22 10:15 | 29    | 27,731  | Tree                |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 06/14/22 18:09 | 1     | 5       | Tree                |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 06/20/22 06:57 | 142   | 36,455  | Tree                |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 06/27/22 15:59 | 1     | 12      | Unknown             |

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|-----|-------|---|-----------|-----|-------|----------------|-------|-----------|--------------------|
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 06/27/22 17:09 | 2     | 221       | Unknown            |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 07/01/22 14:00 | 1     | 6         | AMI - No Job/Cause |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 07/05/22 06:46 | 64    | 7,052     | Equipment          |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 07/08/22 13:39 | 1     | 20        | AMI - No Job/Cause |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 07/18/22 10:14 | 4     | 320       | Animal             |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 07/18/22 10:14 | 3     | 240       | Animal             |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 07/18/22 10:14 | 79    | 6,325     | Animal             |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 07/23/22 08:10 | 88    | 5,659     | Animal             |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 07/23/22 18:17 | 1     | 11        | AMI - No Job/Cause |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 08/02/22 12:35 | 1     | 75        | AMI - No Job/Cause |
| 1A5 | SAIFI | 5 | MACMB8521 | MED |       | 08/03/22 03:15 | 1     | 582       | Wind               |
| 1A5 | SAIFI | 5 | MACMB8521 | MED |       | 08/03/22 03:15 | 5     | 2,908     | Tree               |
| 1A5 | SAIFI | 5 | MACMB8521 | MED | Small | 08/03/22 18:42 | 7     | 7,188     | Tree               |
| 1A5 | SAIFI | 5 | MACMB8521 | MED | Small | 08/03/22 18:42 | 6     | 6,161     | Unknown            |
| 1A5 | SAIFI | 5 | MACMB8521 | MED | Small | 08/03/22 18:42 | 1,929 | 1,981,048 | Wind               |
| 1A5 | SAIFI | 5 | MACMB8521 | MED | Small | 08/03/22 18:42 | 1     | 1,027     | Other              |
| 1A5 | SAIFI | 5 | MACMB8521 | MED | Small | 08/03/22 18:42 | 322   | 330,805   | AMI - No Job/Cause |
| 1A5 | SAIFI | 5 | MACMB8521 | MED | Small | 08/03/22 18:42 | 1     | 1,027     | Unknown            |
| 1A5 | SAIFI | 5 | MACMB8521 | MED | Small | 08/03/22 18:42 | 1     | 1,027     | Other              |
| 1A5 | SAIFI | 5 | MACMB8521 | MED | Small | 08/03/22 18:42 | 1     | 1,027     | Tree               |
| 1A5 | SAIFI | 5 | MACMB8521 | MED | Small | 08/03/22 18:42 | 12    | 12,323    | Wind               |
| 1A5 | SAIFI | 5 | MACMB8521 | MED | Small | 08/03/22 18:42 | 2     | 2,054     | Wind               |
| 1A5 | SAIFI | 5 | MACMB8521 | MED | Small | 08/03/22 18:42 | 1     | 1,027     | Other              |
| 1A5 | SAIFI | 5 | MACMB8521 | -   | Small | 08/04/22 23:20 | 1     | 927       | AMI - No Job/Cause |
| 1A5 | SAIFI | 5 | MACMB8521 | -   | Small | 08/05/22 01:28 | 29    | 12,970    | Wind               |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 08/15/22 15:19 | 30    | 3,809     | Equipment          |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 08/18/22 19:51 | 1     | 282       | Other              |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 08/18/22 19:51 | 1     | 282       | Other              |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 08/18/22 19:51 | 2,051 | 408,521   | Tree               |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 08/18/22 19:51 | 1     | 282       | Unknown            |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 08/18/22 19:51 | 1     | 93        | Unknown            |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 08/18/22 19:52 | 1     | 93        | Unknown            |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 08/19/22 09:34 | 3     | 543       | Equipment          |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 08/27/22 14:23 | 4     | 89        | Unknown            |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 08/27/22 14:23 | 1     | 22        | AMI - No Job/Cause |
| 1A5 | SAIFI | 5 | MACMB8521 | MED | Cat   | 08/29/22 18:26 | 39    | 208,387   | Tree               |
| 1A5 | SAIFI | 5 | MACMB8521 | MED | Cat   | 08/29/22 19:12 | 54    | 293,427   | Tree               |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 09/08/22 23:10 | 649   | 56,389    | Equipment          |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 09/08/22 23:11 | 1     | 87        | Other              |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 09/15/22 14:21 | 1     | 182       | Animal             |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 09/16/22 12:34 | 10    | 256       | Equipment          |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 09/16/22 13:14 | 1     | 23        | AMI - No Job/Cause |
| 1A5 | SAIFI | 5 | MACMB8521 | -   |       | 09/26/22 14:35 | 38    | 11,610    | Tree               |

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|     |       |   |           |   |       |                |       |         |                    |
|-----|-------|---|-----------|---|-------|----------------|-------|---------|--------------------|
| 1A5 | SAIFI | 5 | MACMB8521 | - |       | 10/01/22 10:42 | 1     | 46      | Unknown            |
| 1A5 | SAIFI | 5 | MACMB8521 | - |       | 10/02/22 09:29 | 79    | 27,044  | Intentional        |
| 1A5 | SAIFI | 5 | MACMB8521 | - |       | 10/08/22 12:00 | 2,947 | 481,136 | Animal             |
| 1A5 | SAIFI | 5 | MACMB8521 | - |       | 10/08/22 12:00 | 5     | 793     | Animal             |
| 1A5 | SAIFI | 5 | MACMB8521 | - |       | 10/25/22 09:22 | 1     | 41      | Unknown            |
| 1A5 | SAIFI | 5 | MACMB8521 | - |       | 11/01/22 02:30 | 10    | 1,445   | Equipment          |
| 1A5 | SAIFI | 5 | MACMB8521 | - |       | 11/01/22 02:30 | 1     | 131     | AMI - No Job/Cause |
| 1A5 | SAIFI | 5 | MACMB8521 | - |       | 11/11/22 13:43 | 1     | 6       | Unknown            |
| 1A5 | SAIFI | 5 | MACMB8521 | - |       | 11/14/22 14:18 | 2     | 51      | Unknown            |
| 1A5 | SAIFI | 5 | MACMB8521 | - |       | 11/17/22 17:16 | 12    | 930     | Other              |
| 1A5 | SAIFI | 5 | MACMB8521 | - | Small | 12/23/22 16:05 | 1     | 68      | Unknown            |
| 1A5 | SAIFI | 5 | MACMB8521 | - | Small | 12/23/22 16:05 | 105   | 7,140   | Wind               |

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A number of outages for the circuits in Appendix 1B were recorded by AMI meters but could not be associated with an InService OMS event using current algorithms. As a result, no cause can be directly attributed to these events. These unassociated AMI meter outages account for 3.2% of the customers interrupted and 1.4% of the customer-minutes interrupted for these circuits.

**Appendix 1B**  
**Outage and Cause Listing - SAIFI - Circuit Basis**

| Ref# | Metric | Rank | Circuit   | MED | Storm | Interruption Date/Time | Customers Interrupted | Customer Minutes Interrupted | Cause              |
|------|--------|------|-----------|-----|-------|------------------------|-----------------------|------------------------------|--------------------|
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 01/01/22 16:43         | 288                   | 47,351                       | Tree               |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 01/01/22 16:43         | 532                   | 71,404                       | Tree               |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 01/06/22 08:43         | 1                     | 19                           | Unknown            |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 01/08/22 14:37         | 1                     | 98                           | Equipment          |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 01/10/22 20:25         | 211                   | 20,757                       | Equipment          |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 01/10/22 20:25         | 71                    | 6,990                        | AMI - No Job/Cause |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 01/10/22 23:55         | 396                   | 59,166                       | Tree               |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 01/11/22 00:32         | 165                   | 27,849                       | AMI - No Job/Cause |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 01/11/22 16:04         | 1                     | 17                           | Unknown            |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 01/12/22 15:17         | 1                     | 6                            | Unknown            |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 01/14/22 10:57         | 1                     | 711                          | AMI - No Job/Cause |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 01/21/22 09:41         | 1                     | 375                          | AMI - No Job/Cause |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 01/24/22 12:41         | 1                     | 21                           | AMI - No Job/Cause |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 01/27/22 09:29         | 1                     | 335                          | AMI - No Job/Cause |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 02/21/22 07:04         | 844                   | 170,816                      | Tree               |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 03/06/22 09:12         | 1                     | 366                          | Tree               |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 03/06/22 11:11         | 849                   | 125,732                      | Tree               |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 03/14/22 12:07         | 1                     | 480                          | AMI - No Job/Cause |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 03/15/22 18:32         | 1                     | 16                           | AMI - No Job/Cause |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 03/19/22 07:18         | 1                     | 106                          | AMI - No Job/Cause |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 03/24/22 04:58         | 1                     | 348                          | AMI - No Job/Cause |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 03/24/22 13:37         | 1                     | 270                          | AMI - No Job/Cause |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 03/25/22 21:04         | 1                     | 11                           | AMI - No Job/Cause |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 03/29/22 13:44         | 1                     | 561                          | AMI - No Job/Cause |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   | Small | 03/31/22 08:56         | 1                     | 320                          | AMI - No Job/Cause |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   | Small | 03/31/22 10:50         | 1                     | 350                          | Wind               |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   | Small | 04/01/22 05:32         | 1                     | 501                          | Equipment          |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 04/22/22 10:38         | 25                    | 4,603                        | Equipment          |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 04/26/22 14:32         | 1                     | 44                           | Intentional        |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 04/27/22 12:50         | 6                     | 295                          | Intentional        |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 04/29/22 12:51         | 4                     | 162                          | Intentional        |
| 1B1  | SAIFI  | 1    | WSEND0607 | -   |       | 04/30/22 12:19         | 1                     | 26                           | Intentional        |

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|-----|-------|---|-----------|-----|-------|----------------|-----|---------|--------------------|
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 05/04/22 14:16 | 1   | 27      | Intentional        |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 05/05/22 09:32 | 10  | 1,907   | Intentional        |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 05/07/22 10:06 | 1   | 43      | Unknown            |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 05/07/22 11:51 | 2   | 161     | AMI - No Job/Cause |
| 1B1 | SAIFI | 1 | WSEND0607 | MED | Small | 06/01/22 12:37 | 1   | 118     | AMI - No Job/Cause |
| 1B1 | SAIFI | 1 | WSEND0607 | MED | Small | 06/01/22 13:20 | 4   | 298     | AMI - No Job/Cause |
| 1B1 | SAIFI | 1 | WSEND0607 | MED | Small | 06/01/22 13:20 | 12  | 894     | Wind               |
| 1B1 | SAIFI | 1 | WSEND0607 | -   | Small | 06/02/22 18:48 | 1   | 7       | AMI - No Job/Cause |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 06/07/22 14:45 | 1   | 68      | AMI - No Job/Cause |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 06/07/22 14:50 | 1   | 64      | Equipment          |
| 1B1 | SAIFI | 1 | WSEND0607 | -   | Small | 06/15/22 23:49 | 342 | 269,341 | Wind               |
| 1B1 | SAIFI | 1 | WSEND0607 | -   | Small | 06/15/22 23:49 | 1   | 1,180   | Wind               |
| 1B1 | SAIFI | 1 | WSEND0607 | -   | Small | 06/16/22 16:22 | 445 | 83,461  | Unknown            |
| 1B1 | SAIFI | 1 | WSEND0607 | -   | Small | 06/16/22 16:36 | 11  | 1,907   | Unknown            |
| 1B1 | SAIFI | 1 | WSEND0607 | -   | Small | 06/16/22 16:36 | 10  | 33,102  | Unknown            |
| 1B1 | SAIFI | 1 | WSEND0607 | -   | Small | 06/19/22 00:45 | 802 | 30,663  | Equipment          |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 06/20/22 11:50 | 1   | 6       | Tree               |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 06/21/22 09:31 | 1   | 6       | Unknown            |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 06/28/22 09:47 | 1   | 25      | Unknown            |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 06/28/22 09:47 | 1   | 25      | AMI - No Job/Cause |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 07/14/22 23:28 | 459 | 65,447  | Wind               |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 07/19/22 22:29 | 134 | 10,917  | Loading            |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 07/24/22 17:29 | 7   | 200     | Tree               |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 07/25/22 16:44 | 1   | 11      | Tree               |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 08/06/22 05:13 | 1   | 1,705   | Equipment          |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 08/12/22 22:07 | 1   | 127     | Unknown            |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 08/12/22 22:42 | 802 | 73,672  | Tree               |
| 1B1 | SAIFI | 1 | WSEND0607 | MED | Cat   | 08/29/22 16:51 | 1   | 173     | AMI - No Job/Cause |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 09/11/22 12:46 | 1   | 299     | AMI - No Job/Cause |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 10/16/22 10:59 | 1   | 54      | AMI - No Job/Cause |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 10/17/22 08:32 | 1   | 15      | Equipment          |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 10/27/22 06:41 | 1   | 518     | Other              |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 11/01/22 18:02 | 1   | 1,215   | Unknown            |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 11/02/22 13:46 | 1   | 114     | AMI - No Job/Cause |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 11/02/22 14:19 | 1   | 111     | AMI - No Job/Cause |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 11/02/22 16:38 | 3   | 121     | AMI - No Job/Cause |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 11/04/22 08:53 | 9   | 1,197   | AMI - No Job/Cause |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 11/04/22 10:15 | 1   | 6       | AMI - No Job/Cause |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 11/04/22 11:36 | 1   | 8       | AMI - No Job/Cause |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 11/10/22 15:38 | 6   | 781     | AMI - No Job/Cause |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 11/10/22 15:38 | 1   | 124     | Unknown            |
| 1B1 | SAIFI | 1 | WSEND0607 | -   |       | 12/03/22 08:07 | 16  | 2,876   | Wind               |
| 1B2 | SAIFI | 2 | PURTN1020 | -   |       | 02/08/22 09:49 | 420 | 8,652   | Intentional        |

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|     |       |   |           |     |       |                |       |         |                    |
|-----|-------|---|-----------|-----|-------|----------------|-------|---------|--------------------|
| 1B2 | SAIFI | 2 | PURTN1020 | -   |       | 03/23/22 12:03 | 20    | 8,811   | Tree               |
| 1B2 | SAIFI | 2 | PURTN1020 | -   |       | 04/07/22 11:37 | 20    | 271     | Tree               |
| 1B2 | SAIFI | 2 | PURTN1020 | -   |       | 04/28/22 14:01 | 1     | 21      | Equipment          |
| 1B2 | SAIFI | 2 | PURTN1020 | -   |       | 05/16/22 10:51 | 1     | 24      | Tree               |
| 1B2 | SAIFI | 2 | PURTN1020 | -   |       | 05/16/22 18:06 | 1     | 862     | AMI - No Job/Cause |
| 1B2 | SAIFI | 2 | PURTN1020 | -   |       | 05/25/22 19:01 | 1     | 730     | AMI - No Job/Cause |
| 1B2 | SAIFI | 2 | PURTN1020 | -   |       | 05/30/22 19:36 | 49    | 4,648   | Equipment          |
| 1B2 | SAIFI | 2 | PURTN1020 | -   |       | 05/31/22 20:31 | 1     | 6       | Unknown            |
| 1B2 | SAIFI | 2 | PURTN1020 | -   |       | 06/10/22 15:18 | 633   | 246,582 | Equipment          |
| 1B2 | SAIFI | 2 | PURTN1020 | -   | Small | 06/16/22 08:54 | 1     | 84      | Wind               |
| 1B2 | SAIFI | 2 | PURTN1020 | -   | Small | 06/19/22 18:59 | 1     | 7       | Tree               |
| 1B2 | SAIFI | 2 | PURTN1020 | -   | Small | 06/19/22 18:59 | 1     | 7       | AMI - No Job/Cause |
| 1B2 | SAIFI | 2 | PURTN1020 | -   |       | 07/19/22 22:48 | 1     | 13      | AMI - No Job/Cause |
| 1B2 | SAIFI | 2 | PURTN1020 | MED | Small | 08/03/22 18:33 | 15    | 17,298  | Tree               |
| 1B2 | SAIFI | 2 | PURTN1020 | MED | Cat   | 08/30/22 11:46 | 151   | 22,267  | Wind               |
| 1B2 | SAIFI | 2 | PURTN1020 | MED | Cat   | 08/30/22 17:16 | 1     | 7,058   | Tree               |
| 1B2 | SAIFI | 2 | PURTN1020 | -   | Cat   | 09/02/22 00:43 | 22    | 680     | Tree               |
| 1B2 | SAIFI | 2 | PURTN1020 | -   |       | 09/15/22 09:57 | 1     | 7       | Unknown            |
| 1B2 | SAIFI | 2 | PURTN1020 | -   |       | 09/20/22 19:18 | 2     | 762     | Tree               |
| 1B2 | SAIFI | 2 | PURTN1020 | -   |       | 09/22/22 13:01 | 1     | 6       | AMI - No Job/Cause |
| 1B2 | SAIFI | 2 | PURTN1020 | -   |       | 09/24/22 16:00 | 1     | 185     | AMI - No Job/Cause |
| 1B2 | SAIFI | 2 | PURTN1020 | -   |       | 09/24/22 17:23 | 611   | 62,624  | Tree               |
| 1B2 | SAIFI | 2 | PURTN1020 | -   |       | 09/24/22 18:27 | 17    | 660     | Tree               |
| 1B2 | SAIFI | 2 | PURTN1020 | -   |       | 09/24/22 18:27 | 1     | 38      | AMI - No Job/Cause |
| 1B2 | SAIFI | 2 | PURTN1020 | -   |       | 09/24/22 18:27 | 1     | 38      | Unknown            |
| 1B2 | SAIFI | 2 | PURTN1020 | -   |       | 09/27/22 10:47 | 1     | 28      | Equipment          |
| 1B2 | SAIFI | 2 | PURTN1020 | -   |       | 12/09/22 13:36 | 1     | 1,652   | AMI - No Job/Cause |
| 1B2 | SAIFI | 2 | PURTN1020 | -   |       | 12/18/22 01:23 | 1     | 21      | Equipment          |
| 1B2 | SAIFI | 2 | PURTN1020 | -   |       | 12/21/22 11:02 | 1     | 10      | Unknown            |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 02/05/22 11:12 | 1     | 126     | Other              |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 02/05/22 11:12 | 1,276 | 154,579 | Equipment          |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 02/07/22 11:33 | 1     | 29      | AMI - No Job/Cause |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 02/07/22 23:56 | 1     | 17      | AMI - No Job/Cause |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 02/08/22 09:06 | 1     | 145     | AMI - No Job/Cause |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 02/08/22 17:07 | 1     | 11      | Equipment          |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 02/09/22 12:34 | 3     | 189     | AMI - No Job/Cause |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 02/10/22 13:08 | 2     | 107     | AMI - No Job/Cause |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 02/15/22 11:34 | 4     | 288     | AMI - No Job/Cause |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 02/16/22 11:31 | 1     | 66      | Intentional        |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 03/03/22 21:47 | 1     | 65      | Unknown            |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 03/03/22 21:47 | 1,249 | 81,592  | Unknown            |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 03/03/22 22:11 | 291   | 11,732  | Equipment          |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 03/05/22 10:59 | 1     | 25      | Unknown            |

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|-----|-------|---|-----------|-----|-------|----------------|-------|---------|---------------------|
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 03/27/22 14:42 | 1,376 | 216,997 | Equipment           |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   | Small | 03/31/22 13:12 | 1,985 | 239,334 | Tree                |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 04/03/22 10:39 | 1     | 9       | Unknown             |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 04/05/22 10:57 | 1     | 139     | AMI - No Job/Cause  |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 05/12/22 08:10 | 1     | 124     | AMI - No Job/Cause  |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 05/16/22 17:08 | 1     | 19      | Equipment           |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 05/27/22 13:17 | 1,505 | 45,325  | Equipment           |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 06/10/22 09:12 | 4     | 258     | AMI - No Job/Cause  |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 06/10/22 09:12 | 123   | 7,935   | Unknown             |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 06/11/22 08:25 | 10    | 1,235   | Unknown             |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   | Small | 06/17/22 23:14 | 1     | 2,477   | Tree                |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 06/20/22 16:54 | 1,355 | 302,720 | Tree                |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 06/20/22 16:54 | 1     | 223     | AMI - No Job/Cause  |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 06/21/22 13:00 | 24    | 123     | Intentional         |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 06/28/22 07:13 | 2     | 219     | Animal              |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 06/29/22 12:27 | 2     | 174     | Animal              |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 07/07/22 00:05 | 1     | 10      | Equipment           |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 07/09/22 17:01 | 1     | 169     | Equipment           |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 07/16/22 07:20 | 10    | 1,028   | Equipment           |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 07/24/22 17:35 | 24    | 1,957   | Wind                |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 07/25/22 12:53 | 4     | 158     | Unknown             |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 08/16/22 10:25 | 1     | 410     | Animal              |
| 1B3 | SAIFI | 3 | BUNRT8426 | MED | Cat   | 08/29/22 18:26 | 1     | 1,380   | Unknown             |
| 1B3 | SAIFI | 3 | BUNRT8426 | MED | Cat   | 08/29/22 21:56 | 361   | 231,860 | Wind                |
| 1B3 | SAIFI | 3 | BUNRT8426 | MED | Cat   | 08/29/22 22:45 | 7     | 4,225   | Other               |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   | Cat   | 09/01/22 13:34 | 120   | 38,302  | Equipment           |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   | Cat   | 09/01/22 13:34 | 1,423 | 358,946 | Other               |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   | Cat   | 09/01/22 13:34 | 1     | 319     | Unknown             |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 09/08/22 18:58 | 56    | 11,346  | Equipment           |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 09/20/22 01:55 | 1     | 151     | Other               |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 09/20/22 01:55 | 1     | 151     | Other               |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 09/20/22 01:55 | 277   | 41,801  | Unknown             |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 09/20/22 02:56 | 1,278 | 114,874 | Equipment           |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 10/02/22 10:07 | 1     | 7       | Tree                |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 10/06/22 22:36 | 1     | 614     | Tree                |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 10/14/22 09:51 | 10    | 524     | Animal              |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 10/18/22 11:21 | 3     | 68      | Intentional         |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 10/20/22 14:46 | 1     | 20      | Unknown             |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 10/20/22 19:59 | 25    | 979     | Other Utility       |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 10/22/22 17:26 | 1     | 13      | Unknown             |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 10/26/22 05:19 | 1     | 356     | Public Interference |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 10/28/22 13:41 | 10    | 335     | Animal              |
| 1B3 | SAIFI | 3 | BUNRT8426 | -   |       | 11/09/22 08:06 | 1     | 161     | AMI - No Job/Cause  |



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|-----|-------|---|-----------|-----|-----|----------------|-----|---------|---------------------|
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 05/27/22 19:00 | 2   | 36      | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 05/27/22 19:00 | 1   | 18      | Tree                |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 07/15/22 19:20 | 1   | 247     | Unknown             |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 07/15/22 19:21 | 1   | 247     | Public Interference |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 07/15/22 21:03 | 340 | 49,485  | Public Interference |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 07/15/22 23:05 | 6   | 132     | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 07/15/22 23:05 | 1   | 22      | Public Interference |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 07/16/22 00:02 | 1   | 12      | Public Interference |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 07/16/22 00:02 | 1   | 12      | Other               |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 07/16/22 00:02 | 92  | 1,084   | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 07/16/22 00:02 | 1   | 12      | Public Interference |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 07/19/22 03:12 | 221 | 3,233   | Unknown             |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 07/19/22 04:37 | 4   | 65      | Unknown             |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 07/28/22 15:13 | 1   | 49      | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 07/28/22 16:38 | 1   | 107     | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 07/29/22 08:22 | 1   | 259     | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 07/29/22 17:10 | 1   | 463     | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | MED | Cat | 08/29/22 22:12 | 1   | 7,087   | Other               |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   | Cat | 09/04/22 00:24 | 1   | 8       | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 09/30/22 11:25 | 1   | 427     | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 10/01/22 20:48 | 1   | 890     | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 10/02/22 12:28 | 1   | 17      | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 10/02/22 17:18 | 1   | 255     | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 10/03/22 09:01 | 1   | 219     | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 10/03/22 15:54 | 1   | 18      | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 10/04/22 23:30 | 3   | 57      | Intentional         |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 10/06/22 15:31 | 1   | 29      | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 10/06/22 18:33 | 1   | 844     | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 10/07/22 13:08 | 1   | 1,428   | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 10/08/22 16:16 | 207 | 118,612 | Equipment           |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 10/09/22 08:46 | 1   | 8       | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 10/10/22 11:27 | 3   | 212     | Intentional         |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 10/10/22 13:45 | 1   | 12      | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 10/11/22 13:32 | 1   | 11      | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 10/12/22 13:32 | 1   | 13      | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 10/13/22 13:06 | 1   | 18      | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 10/17/22 06:18 | 1   | 9       | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 10/18/22 14:18 | 1   | 18      | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 10/19/22 13:09 | 1   | 19      | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 10/19/22 15:13 | 1   | 19      | Unknown             |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 10/20/22 09:34 | 3   | 79      | AMI - No Job/Cause  |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 10/22/22 09:20 | 6   | 204     | Intentional         |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |     | 10/22/22 13:04 | 1   | 38      | Intentional         |

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|-----|-------|---|-----------|-----|-------|----------------|-----|---------|--------------------|
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |       | 10/23/22 13:18 | 1   | 472     | AMI - No Job/Cause |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |       | 10/24/22 13:11 | 1   | 237     | AMI - No Job/Cause |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |       | 10/25/22 00:00 | 221 | 12,240  | Intentional        |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |       | 10/26/22 00:02 | 221 | 17,238  | Equipment          |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |       | 10/27/22 11:45 | 20  | 1,884   | Intentional        |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |       | 10/27/22 12:13 | 1   | 82      | Intentional        |
| 1B4 | SAIFI | 4 | MCGRW1321 | MED | Small | 11/05/22 21:00 | 2   | 1,912   | AMI - No Job/Cause |
| 1B4 | SAIFI | 4 | MCGRW1321 | MED | Small | 11/05/22 21:00 | 1   | 956     | Other              |
| 1B4 | SAIFI | 4 | MCGRW1321 | MED | Small | 11/05/22 21:00 | 1   | 956     | Wind               |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |       | 11/10/22 13:31 | 1   | 19      | AMI - No Job/Cause |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |       | 11/15/22 17:23 | 1   | 29      | AMI - No Job/Cause |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |       | 11/18/22 02:44 | 93  | 34,303  | Unknown            |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |       | 11/18/22 02:50 | 97  | 33,842  | Tree               |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |       | 11/18/22 23:34 | 233 | 9,909   | Wind               |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |       | 11/19/22 07:16 | 1   | 13      | AMI - No Job/Cause |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |       | 11/20/22 00:05 | 4   | 49      | Equipment          |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |       | 11/21/22 05:14 | 1   | 543     | AMI - No Job/Cause |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |       | 11/21/22 15:35 | 1   | 5       | AMI - No Job/Cause |
| 1B4 | SAIFI | 4 | MCGRW1321 | -   |       | 11/25/22 09:26 | 5   | 270     | AMI - No Job/Cause |
| 1B5 | SAIFI | 5 | TWEMI1939 | -   |       | 01/04/22 11:39 | 1   | 6       | AMI - No Job/Cause |
| 1B5 | SAIFI | 5 | TWEMI1939 | -   |       | 01/14/22 10:33 | 841 | 94,889  | Tree               |
| 1B5 | SAIFI | 5 | TWEMI1939 | -   |       | 05/10/22 14:34 | 839 | 8,728   | Unknown            |
| 1B5 | SAIFI | 5 | TWEMI1939 | -   |       | 05/16/22 09:17 | 816 | 365,657 | Tree               |
| 1B5 | SAIFI | 5 | TWEMI1939 | -   | Small | 06/17/22 08:28 | 1   | 202     | AMI - No Job/Cause |
| 1B5 | SAIFI | 5 | TWEMI1939 | -   |       | 08/01/22 04:21 | 15  | 1,991   | Tree               |
| 1B5 | SAIFI | 5 | TWEMI1939 | MED | Small | 08/03/22 21:08 | 105 | 103,703 | Wind               |
| 1B5 | SAIFI | 5 | TWEMI1939 | MED | Small | 08/03/22 23:57 | 9   | 12,200  | AMI - No Job/Cause |
| 1B5 | SAIFI | 5 | TWEMI1939 | MED | Small | 08/04/22 00:02 | 3   | 4,050   | AMI - No Job/Cause |
| 1B5 | SAIFI | 5 | TWEMI1939 | MED | Small | 08/04/22 01:09 | 122 | 120,428 | Equipment          |
| 1B5 | SAIFI | 5 | TWEMI1939 | MED | Small | 08/04/22 03:51 | 523 | 453,431 | Tree               |
| 1B5 | SAIFI | 5 | TWEMI1939 | MED | Small | 08/04/22 04:26 | 1   | 887     | Wind               |
| 1B5 | SAIFI | 5 | TWEMI1939 | -   |       | 08/08/22 18:35 | 66  | 110,633 | Equipment          |
| 1B5 | SAIFI | 5 | TWEMI1939 | -   |       | 08/08/22 18:35 | 219 | 364,865 | Equipment          |
| 1B5 | SAIFI | 5 | TWEMI1939 | -   |       | 08/12/22 00:11 | 2   | 20      | AMI - No Job/Cause |
| 1B5 | SAIFI | 5 | TWEMI1939 | -   |       | 08/12/22 00:11 | 2   | 21      | Equipment          |
| 1B5 | SAIFI | 5 | TWEMI1939 | -   |       | 08/14/22 02:17 | 839 | 31,281  | Unknown            |
| 1B5 | SAIFI | 5 | TWEMI1939 | -   |       | 08/20/22 18:34 | 1   | 88      | Tree               |
| 1B5 | SAIFI | 5 | TWEMI1939 | -   |       | 08/20/22 18:34 | 2   | 175     | AMI - No Job/Cause |
| 1B5 | SAIFI | 5 | TWEMI1939 | -   |       | 08/20/22 18:34 | 1   | 88      | Tree               |
| 1B5 | SAIFI | 5 | TWEMI1939 | -   |       | 08/21/22 04:19 | 16  | 4,899   | Intentional        |
| 1B5 | SAIFI | 5 | TWEMI1939 | -   |       | 08/21/22 04:19 | 828 | 254,014 | Tree               |
| 1B5 | SAIFI | 5 | TWEMI1939 | -   |       | 08/21/22 23:59 | 5   | 82      | AMI - No Job/Cause |
| 1B5 | SAIFI | 5 | TWEMI1939 | -   |       | 08/22/22 00:00 | 1   | 9       | Unknown            |

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|     |       |   |           |   |  |                |     |       |                     |
|-----|-------|---|-----------|---|--|----------------|-----|-------|---------------------|
| 1B5 | SAIFI | 5 | TWEMI1939 | - |  | 08/22/22 00:00 | 374 | 3,302 | Intentional         |
| 1B5 | SAIFI | 5 | TWEMI1939 | - |  | 08/22/22 00:00 | 462 | 4,127 | AMI - No Job/Cause  |
| 1B5 | SAIFI | 5 | TWEMI1939 | - |  | 08/22/22 00:00 | 1   | 9     | Unknown             |
| 1B5 | SAIFI | 5 | TWEMI1939 | - |  | 09/16/22 06:04 | 2   | 585   | Public Interference |
| 1B5 | SAIFI | 5 | TWEMI1939 | - |  | 10/24/22 15:13 | 1   | 37    | AMI - No Job/Cause  |
| 1B5 | SAIFI | 5 | TWEMI1939 | - |  | 11/08/22 09:23 | 30  | 530   | Intentional         |
| 1B5 | SAIFI | 5 | TWEMI1939 | - |  | 11/29/22 11:47 | 4   | 193   | AMI - No Job/Cause  |
| 1B5 | SAIFI | 5 | TWEMI1939 | - |  | 11/30/22 13:54 | 3   | 223   | AMI - No Job/Cause  |
| 1B5 | SAIFI | 5 | TWEMI1939 | - |  | 11/30/22 13:56 | 1   | 63    | Intentional         |
| 1B5 | SAIFI | 5 | TWEMI1939 | - |  | 12/02/22 10:31 | 1   | 5     | Unknown             |
| 1B5 | SAIFI | 5 | TWEMI1939 | - |  | 12/03/22 08:06 | 1   | 559   | Equipment           |
| 1B5 | SAIFI | 5 | TWEMI1939 | - |  | 12/09/22 18:44 | 1   | 10    | Unknown             |
| 1B5 | SAIFI | 5 | TWEMI1939 | - |  | 12/10/22 09:50 | 1   | 33    | AMI - No Job/Cause  |
| 1B5 | SAIFI | 5 | TWEMI1939 | - |  | 12/30/22 21:48 | 1   | 1,155 | Tree                |

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A number of outages for the circuits in Appendix 2A were recorded by AMI meters but could not be associated with an InService OMS event using current algorithms. As a result, no cause can be directly attributed to these events. These unassociated AMI meter outages account for 1.6% of the customers interrupted and 0.2% of the customer-minutes interrupted for these circuits.

**Appendix 2A**  
**Outage and Cause Listing - SAIDI - System Basis**

| Ref# | Metric | Rank | Circuit   | MED | Storm | Interruption Date/Time | Customers Interrupted | Customer Minutes Interrupted | Cause              |
|------|--------|------|-----------|-----|-------|------------------------|-----------------------|------------------------------|--------------------|
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 01/04/22 10:30         | 1                     | 113                          | Animal             |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 02/01/22 14:48         | 1                     | 201                          | AMI - No Job/Cause |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 02/06/22 13:19         | 1                     | 236                          | Equipment          |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 02/08/22 14:45         | 1                     | 162                          | AMI - No Job/Cause |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 02/08/22 14:45         | 1                     | 162                          | Equipment          |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 02/13/22 10:50         | 3                     | 131                          | Other              |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 02/13/22 10:50         | 66                    | 2,905                        | Animal             |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 02/14/22 11:54         | 1                     | 253                          | Equipment          |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 02/19/22 01:18         | 1                     | 696                          | Equipment          |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 02/19/22 09:53         | 1                     | 5                            | AMI - No Job/Cause |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 02/21/22 10:18         | 1                     | 5                            | AMI - No Job/Cause |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 02/23/22 13:48         | 1                     | 5                            | AMI - No Job/Cause |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 02/24/22 10:46         | 1                     | 7                            | AMI - No Job/Cause |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 03/01/22 08:39         | 1                     | 5                            | AMI - No Job/Cause |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 03/01/22 08:40         | 49                    | 5,651                        | Equipment          |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 03/02/22 05:38         | 1                     | 264                          | Unknown            |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 03/03/22 12:34         | 1                     | 143                          | AMI - No Job/Cause |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 03/08/22 14:32         | 120                   | 11,889                       | Tree               |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 03/09/22 10:42         | 1                     | 145                          | AMI - No Job/Cause |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 03/09/22 11:39         | 1                     | 199                          | AMI - No Job/Cause |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 03/10/22 09:46         | 1                     | 115                          | Equipment          |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 03/10/22 09:46         | 1                     | 115                          | Equipment          |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 03/10/22 09:46         | 2                     | 231                          | AMI - No Job/Cause |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 03/14/22 05:36         | 1                     | 40                           | Equipment          |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 03/18/22 23:38         | 2                     | 49                           | AMI - No Job/Cause |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 03/20/22 00:03         | 1                     | 5                            | AMI - No Job/Cause |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 03/20/22 09:43         | 22                    | 1,986                        | Equipment          |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 03/20/22 10:01         | 1                     | 155                          | AMI - No Job/Cause |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 03/20/22 19:47         | 1                     | 82                           | AMI - No Job/Cause |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 03/21/22 17:41         | 1                     | 10                           | Unknown            |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 03/24/22 16:11         | 74                    | 10,711                       | Equipment          |
| 2A1  | SAIDI  | 1    | CONRD8130 | -   |       | 03/29/22 10:02         | 1                     | 128                          | AMI - No Job/Cause |

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|-----|-------|---|-----------|---|-------|----------------|-----|-------|--------------------|
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 03/29/22 15:29 | 5   | 469   | Equipment          |
| 2A1 | SAIDI | 1 | CONRD8130 | - | Small | 04/01/22 07:04 | 1   | 6     | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 04/06/22 10:48 | 1   | 54    | Tree               |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 04/06/22 10:48 | 1   | 54    | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 04/06/22 18:23 | 1   | 29    | Unknown            |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 04/07/22 09:31 | 2   | 199   | Unknown            |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 04/08/22 12:10 | 1   | 77    | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 04/09/22 17:54 | 1   | 5     | Unknown            |
| 2A1 | SAIDI | 1 | CONRD8130 | - | Small | 04/14/22 06:55 | 1   | 217   | Equipment          |
| 2A1 | SAIDI | 1 | CONRD8130 | - | Small | 04/14/22 14:21 | 32  | 9,561 | Wind               |
| 2A1 | SAIDI | 1 | CONRD8130 | - | Small | 04/14/22 20:56 | 1   | 11    | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | - | Small | 04/14/22 21:17 | 1   | 12    | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | - | Small | 04/14/22 23:13 | 1   | 49    | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | - | Small | 04/15/22 15:48 | 1   | 123   | Unknown            |
| 2A1 | SAIDI | 1 | CONRD8130 | - | Small | 04/15/22 15:49 | 2   | 107   | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | - | Small | 04/15/22 15:49 | 112 | 7,152 | Equipment          |
| 2A1 | SAIDI | 1 | CONRD8130 | - | Small | 04/15/22 15:49 | 1   | 125   | Wind               |
| 2A1 | SAIDI | 1 | CONRD8130 | - | Small | 04/15/22 19:41 | 2   | 12    | Wind               |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 04/17/22 12:58 | 1   | 41    | Other              |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 04/17/22 12:58 | 1   | 41    | Tree               |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 04/17/22 12:58 | 4   | 165   | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 04/20/22 11:47 | 1   | 16    | Unknown            |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 04/26/22 09:53 | 2   | 104   | Other              |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 04/28/22 05:05 | 1   | 6     | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 05/02/22 09:37 | 1   | 778   | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 05/02/22 09:37 | 1   | 778   | Animal             |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 05/03/22 06:05 | 1   | 12    | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 05/03/22 12:58 | 4   | 315   | Equipment          |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 05/03/22 19:00 | 2   | 17    | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 05/03/22 19:00 | 1   | 8     | Unknown            |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 05/06/22 09:36 | 1   | 6     | Unknown            |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 05/10/22 10:09 | 2   | 34    | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 05/12/22 06:49 | 1   | 255   | Animal             |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 05/12/22 18:23 | 1   | 529   | Equipment          |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 05/16/22 18:01 | 1   | 36    | Equipment          |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 05/19/22 10:13 | 2   | 264   | Animal             |
| 2A1 | SAIDI | 1 | CONRD8130 | - | Small | 05/21/22 09:59 | 1   | 5     | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | - | Small | 05/21/22 10:00 | 49  | 8,406 | Lightning          |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 05/23/22 08:32 | 1   | 170   | Animal             |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 05/28/22 09:21 | 1   | 60    | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 05/29/22 07:13 | 1   | 157   | Equipment          |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 05/30/22 17:48 | 1   | 136   | Unknown            |
| 2A1 | SAIDI | 1 | CONRD8130 | - |       | 05/30/22 17:52 | 55  | 8,766 | Equipment          |

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|-----|-------|---|-----------|-----|-------|----------------|-----|--------|---------------------|
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 05/31/22 00:56 | 5   | 138    | Equipment           |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 05/31/22 14:47 | 2   | 96     | Intentional         |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Small | 06/01/22 14:56 | 1   | 38     | AMI - No Job/Cause  |
| 2A1 | SAIDI | 1 | CONRD8130 | -   | Small | 06/02/22 14:28 | 1   | 107    | AMI - No Job/Cause  |
| 2A1 | SAIDI | 1 | CONRD8130 | -   | Small | 06/03/22 14:03 | 1   | 3,300  | Tree                |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/03/22 20:58 | 2   | 132    | Animal              |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/04/22 09:52 | 5   | 212    | Equipment           |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/06/22 08:46 | 1   | 317    | AMI - No Job/Cause  |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/06/22 13:25 | 119 | 7,722  | Unknown             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/07/22 11:14 | 2   | 701    | Animal              |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/07/22 11:53 | 1   | 128    | Animal              |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/10/22 20:40 | 49  | 29,834 | Public Interference |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/10/22 20:40 | 1   | 180    | Unknown             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/13/22 09:12 | 1   | 126    | AMI - No Job/Cause  |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/13/22 09:12 | 1   | 126    | Unknown             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/14/22 00:31 | 6   | 2,824  | Lightning           |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/14/22 01:08 | 22  | 3,362  | Equipment           |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/14/22 02:15 | 1   | 602    | Equipment           |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/15/22 03:08 | 10  | 216    | Equipment           |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/15/22 09:23 | 1   | 28     | AMI - No Job/Cause  |
| 2A1 | SAIDI | 1 | CONRD8130 | -   | Small | 06/16/22 07:21 | 2   | 708    | Unknown             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   | Small | 06/17/22 08:55 | 1   | 292    | Animal              |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/20/22 03:15 | 3   | 1,626  | Equipment           |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/20/22 03:15 | 45  | 6,801  | AMI - No Job/Cause  |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/20/22 05:47 | 26  | 197    | AMI - No Job/Cause  |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/20/22 10:05 | 1   | 6      | AMI - No Job/Cause  |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/20/22 11:35 | 2   | 146    | Tree                |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/20/22 14:13 | 1   | 28     | AMI - No Job/Cause  |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/22/22 11:27 | 1   | 170    | AMI - No Job/Cause  |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/22/22 11:28 | 1   | 170    | Equipment           |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/23/22 21:18 | 1   | 69     | AMI - No Job/Cause  |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/24/22 06:39 | 118 | 16,887 | Tree                |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/24/22 07:53 | 1   | 156    | Animal              |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/27/22 07:57 | 1   | 322    | AMI - No Job/Cause  |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/27/22 07:57 | 1   | 322    | Tree                |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/27/22 09:45 | 1   | 158    | Animal              |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/29/22 11:21 | 1   | 465    | Unknown             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 06/30/22 15:32 | 1   | 199    | Unknown             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 07/02/22 07:35 | 49  | 4,792  | Tree                |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 07/02/22 08:35 | 1   | 504    | Animal              |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 07/03/22 10:12 | 1   | 165    | Equipment           |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 07/05/22 20:57 | 47  | 8,044  | Tree                |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 07/05/22 20:57 | 1   | 171    | Other               |

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|-----|-------|---|-----------|-----|-------|----------------|-------|-----------|--------------------|
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 07/06/22 13:11 | 30    | 3,547     | Animal             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 07/06/22 19:58 | 25    | 1,710     | Animal             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 07/06/22 19:58 | 1     | 5         | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 07/08/22 16:19 | 1     | 66        | Animal             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 07/10/22 12:53 | 23    | 1,591     | Animal             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 07/11/22 19:01 | 1     | 78        | Animal             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 07/12/22 10:29 | 1     | 565       | Animal             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 07/12/22 20:15 | 1     | 14        | Animal             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 07/13/22 02:17 | 1     | 104       | Animal             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 07/13/22 12:07 | 1     | 75        | Tree               |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 07/14/22 12:35 | 11    | 710       | Tree               |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 07/14/22 12:35 | 2     | 129       | Other              |
| 2A1 | SAIDI | 1 | CONRD8130 | -   | Small | 07/21/22 08:26 | 2     | 415       | Animal             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 07/22/22 08:52 | 4     | 509       | Unknown            |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 07/24/22 04:46 | 24    | 8,664     | Lightning          |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 07/24/22 18:43 | 1     | 358       | Equipment          |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 07/25/22 21:54 | 2     | 222       | Animal             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 07/26/22 07:48 | 1     | 5         | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Small | 08/04/22 17:43 | 1     | 432       | Lightning          |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Small | 08/04/22 17:43 | 1     | 1,416     | Equipment          |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Small | 08/04/22 17:43 | 3     | 1,273     | Lightning          |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 08/07/22 16:34 | 2     | 851       | Tree               |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 08/10/22 10:25 | 1     | 63        | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 08/12/22 17:49 | 1     | 149       | Animal             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 08/14/22 19:36 | 1     | 113       | Unknown            |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 08/18/22 10:40 | 1     | 378       | Equipment          |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 08/18/22 11:25 | 16    | 1,484     | Animal             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 08/18/22 11:25 | 3     | 277       | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 08/19/22 09:32 | 1     | 7         | Unknown            |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 08/24/22 11:48 | 1     | 5         | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 08/24/22 15:13 | 2     | 461       | Equipment          |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 08/24/22 15:13 | 1     | 230       | Unknown            |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 08/25/22 14:40 | 2     | 103       | Equipment          |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 08/27/22 11:36 | 1     | 27        | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 08/29/22 09:50 | 1     | 71        | Animal             |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Cat   | 08/29/22 17:17 | 9     | 59,616    | Tree               |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Cat   | 08/29/22 17:20 | 1     | 1,205     | Wind               |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Cat   | 08/29/22 17:20 | 1     | 5,830     | Unknown            |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Cat   | 08/29/22 17:20 | 47    | 56,641    | Tree               |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Cat   | 08/29/22 17:20 | 3     | 17,492    | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Cat   | 08/29/22 17:20 | 2,300 | 2,900,700 | Tree               |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Cat   | 08/29/22 17:20 | 15    | 19,073    | Wind               |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Cat   | 08/29/22 17:20 | 7     | 40,813    | Wind               |

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|     |       |   |           |     |     |                |       |         |                    |
|-----|-------|---|-----------|-----|-----|----------------|-------|---------|--------------------|
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Cat | 08/29/22 17:20 | 38    | 214,402 | Wind               |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Cat | 08/29/22 17:20 | 1     | 5,831   | Wind               |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Cat | 08/29/22 17:20 | 10    | 58,306  | Wind               |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Cat | 08/29/22 17:20 | 1     | 5,831   | Wind               |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Cat | 08/29/22 17:20 | 1     | 1,205   | Wind               |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Cat | 08/29/22 17:20 | 1     | 5,831   | Wind               |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Cat | 08/29/22 17:20 | 1     | 5,831   | Wind               |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Cat | 08/29/22 17:20 | 1     | 1,205   | Unknown            |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Cat | 08/29/22 17:20 | 1     | 5,831   | Wind               |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Cat | 08/29/22 17:20 | 1     | 5,831   | Wind               |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Cat | 08/31/22 02:40 | 24    | 75,506  | Wind               |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Cat | 08/31/22 08:38 | 10    | 30,865  | Wind               |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Cat | 08/31/22 12:48 | 1     | 34      | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | -   | Cat | 09/01/22 12:47 | 1     | 4,218   | Wind               |
| 2A1 | SAIDI | 1 | CONRD8130 | -   | Cat | 09/01/22 13:03 | 1     | 3,224   | Animal             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   | Cat | 09/02/22 08:35 | 1     | 1,514   | Tree               |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/07/22 11:21 | 76    | 8,285   | Unknown            |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/08/22 13:11 | 1     | 199     | Animal             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/09/22 19:55 | 1     | 231     | Wind               |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/10/22 18:05 | 2     | 2,093   | Tree               |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/11/22 20:09 | 2     | 617     | Unknown            |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/12/22 00:03 | 1     | 897     | Tree               |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/12/22 00:04 | 1     | 897     | Tree               |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/12/22 00:04 | 1     | 897     | Other              |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/12/22 00:04 | 2     | 1,793   | Other              |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/12/22 00:04 | 1     | 897     | Tree               |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/12/22 00:04 | 1     | 897     | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/13/22 11:33 | 3     | 568     | Intentional        |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/14/22 01:19 | 1     | 599     | Animal             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/14/22 12:33 | 2     | 192     | Other              |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/18/22 09:22 | 1     | 145     | Equipment          |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/19/22 05:02 | 1     | 560     | Equipment          |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/19/22 05:02 | 2     | 1,134   | Equipment          |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/20/22 17:11 | 276   | 38,678  | Lightning          |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/20/22 17:12 | 1     | 1,365   | Other              |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/20/22 17:12 | 2     | 2,729   | Tree               |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/20/22 17:12 | 1     | 1,365   | Other              |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/20/22 17:12 | 2     | 2,729   | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/20/22 17:12 | 1     | 1,365   | Other              |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/20/22 17:53 | 1,292 | 494,774 | Tree               |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/20/22 18:38 | 1     | 254     | Unknown            |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/20/22 18:38 | 1     | 254     | Unknown            |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |     | 09/20/22 20:17 | 1     | 2,391   | Wind               |



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|     |       |   |           |     |       |                |       |           |                    |
|-----|-------|---|-----------|-----|-------|----------------|-------|-----------|--------------------|
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 09/22/22 15:53 | 5     | 72        | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 09/23/22 09:05 | 1     | 559       | Animal             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 09/26/22 09:13 | 1     | 21        | Unknown            |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 10/02/22 11:48 | 1     | 519       | Equipment          |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 10/06/22 17:49 | 1     | 6         | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 10/06/22 21:13 | 1     | 145       | Tree               |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 10/14/22 11:24 | 1     | 311       | Animal             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 10/15/22 02:08 | 1     | 550       | Unknown            |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 10/18/22 22:10 | 1     | 14        | Unknown            |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 10/20/22 08:34 | 1     | 18        | Tree               |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 10/20/22 08:34 | 1     | 18        | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 10/20/22 09:06 | 1     | 10        | Tree               |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 10/22/22 15:50 | 2     | 82        | Equipment          |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 10/24/22 14:50 | 1     | 31        | Unknown            |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 10/28/22 14:47 | 2     | 122       | Animal             |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 10/30/22 10:52 | 2     | 224       | Equipment          |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 11/04/22 09:44 | 1     | 176       | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Small | 11/05/22 18:39 | 2,660 | 5,917,721 | Tree               |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Small | 11/05/22 18:45 | 1     | 1,514     | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | MED | Small | 11/05/22 19:01 | 3     | 7,874     | Wind               |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 11/11/22 09:32 | 1     | 6         | Other              |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 11/11/22 09:32 | 65    | 377       | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 11/11/22 09:32 | 1     | 6         | Other              |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 11/11/22 09:32 | 1     | 6         | Other              |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 11/11/22 09:32 | 1     | 6         | Other              |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 12/01/22 11:08 | 2     | 298       | Equipment          |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 12/03/22 07:24 | 1     | 560       | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 12/03/22 07:24 | 1     | 560       | Wind               |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 12/03/22 07:24 | 2     | 1,119     | Wind               |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 12/08/22 11:10 | 1     | 8         | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 12/14/22 11:05 | 1     | 64        | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 12/21/22 09:54 | 1     | 275       | AMI - No Job/Cause |
| 2A1 | SAIDI | 1 | CONRD8130 | -   |       | 12/28/22 14:50 | 1     | 41        | Unknown            |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 02/15/22 16:03 | 1     | 339       | AMI - No Job/Cause |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 02/17/22 11:43 | 1     | 219       | Unknown            |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 02/17/22 11:45 | 1     | 217       | AMI - No Job/Cause |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 03/02/22 20:22 | 1     | 21        | Unknown            |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 03/17/22 16:53 | 1     | 65        | AMI - No Job/Cause |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   | Small | 04/01/22 16:53 | 1     | 7         | AMI - No Job/Cause |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 04/07/22 10:40 | 5     | 182       | AMI - No Job/Cause |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 04/07/22 10:40 | 1     | 36        | Intentional        |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 04/10/22 17:16 | 1     | 994       | Unknown            |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 04/20/22 12:51 | 1     | 34        | Other              |

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|-----|-------|---|-----------|-----|-------|----------------|-------|-----------|---------------------|
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 04/23/22 15:00 | 55    | 4,510     | Equipment           |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 04/29/22 13:42 | 1     | 51        | AMI - No Job/Cause  |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 05/01/22 14:37 | 3     | 220       | AMI - No Job/Cause  |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 05/11/22 09:58 | 1     | 48        | AMI - No Job/Cause  |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 05/13/22 10:34 | 1     | 82        | Public Interference |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 05/28/22 17:37 | 1     | 63        | AMI - No Job/Cause  |
| 2A2 | SAIDI | 2 | SLOAN8524 | MED | Small | 06/02/22 11:24 | 1     | 143       | Tree                |
| 2A2 | SAIDI | 2 | SLOAN8524 | MED | Small | 06/02/22 11:24 | 1     | 143       | AMI - No Job/Cause  |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   | Small | 06/02/22 12:13 | 7     | 660       | AMI - No Job/Cause  |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   | Small | 06/02/22 12:13 | 1     | 94        | Tree                |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 06/14/22 02:03 | 4     | 1,769     | Equipment           |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 06/14/22 09:12 | 1     | 5         | AMI - No Job/Cause  |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   | Small | 06/18/22 15:29 | 1     | 408       | AMI - No Job/Cause  |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 06/23/22 10:30 | 1     | 119       | AMI - No Job/Cause  |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 06/26/22 09:35 | 131   | 5,274     | Animal              |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 07/02/22 07:47 | 1     | 139       | Unknown             |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 07/02/22 07:47 | 5     | 696       | Unknown             |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 07/02/22 07:47 | 1     | 139       | AMI - No Job/Cause  |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 07/07/22 17:19 | 1     | 451       | AMI - No Job/Cause  |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 07/08/22 10:02 | 1     | 274       | AMI - No Job/Cause  |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 07/08/22 15:37 | 1     | 9         | AMI - No Job/Cause  |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 07/17/22 08:54 | 1     | 75        | AMI - No Job/Cause  |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 07/17/22 08:54 | 6     | 453       | Unknown             |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 07/25/22 14:28 | 14    | 2,413     | Animal              |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 08/02/22 10:44 | 1     | 9         | Unknown             |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 08/07/22 10:28 | 7     | 534       | Loading             |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 08/10/22 19:49 | 1     | 32        | Other               |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 08/14/22 09:37 | 2     | 88        | Unknown             |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 08/18/22 12:37 | 1     | 6         | AMI - No Job/Cause  |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 08/19/22 15:20 | 1     | 216       | AMI - No Job/Cause  |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 08/22/22 11:30 | 665   | 21,607    | Equipment           |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 08/26/22 14:21 | 1     | 15        | Equipment           |
| 2A2 | SAIDI | 2 | SLOAN8524 | MED | Cat   | 08/29/22 18:12 | 1,817 | 8,688,118 | Tree                |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   | Cat   | 09/01/22 17:45 | 254   | 2,286     | Tree                |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   | Cat   | 09/01/22 17:45 | 1     | 9         | Unknown             |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   | Cat   | 09/02/22 17:57 | 1     | 19        | Equipment           |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 09/05/22 13:14 | 6     | 1,656     | Public Interference |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 09/05/22 16:33 | 2     | 162       | Public Interference |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 09/07/22 18:28 | 47    | 1,274     | Tree                |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 09/12/22 12:04 | 1     | 106       | Unknown             |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 09/13/22 14:41 | 1     | 134       | Unknown             |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 09/20/22 09:15 | 6     | 2,838     | Animal              |
| 2A2 | SAIDI | 2 | SLOAN8524 | -   |       | 09/27/22 12:11 | 1     | 80        | Equipment           |

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|-----|-------|---|-----------|---|-------|----------------|-------|--------|--------------------|
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 09/27/22 12:38 | 677   | 36,392 | Tree               |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 09/27/22 13:10 | 11    | 243    | Other              |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 09/28/22 18:58 | 24    | 2,201  | Unknown            |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 09/28/22 18:58 | 1     | 92     | Unknown            |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 09/28/22 18:58 | 1     | 92     | Equipment          |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 09/28/22 19:25 | 666   | 43,053 | Equipment          |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 09/28/22 19:55 | 1     | 35     | Unknown            |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 09/28/22 19:55 | 1     | 35     | Equipment          |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 10/02/22 04:57 | 2     | 347    | Tree               |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 10/02/22 07:30 | 5     | 99     | Intentional        |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 10/02/22 07:31 | 1     | 20     | AMI - No Job/Cause |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 10/08/22 10:37 | 10    | 555    | Unknown            |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 10/13/22 18:25 | 2,242 | 95,004 | Tree               |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 10/13/22 18:45 | 1     | 23     | Other              |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 10/13/22 18:45 | 1     | 23     | Other              |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 10/13/22 18:45 | 1     | 23     | Other              |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 10/13/22 18:45 | 1     | 23     | Other              |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 10/13/22 18:45 | 1     | 23     | Other              |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 10/16/22 09:27 | 1     | 46     | AMI - No Job/Cause |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 10/16/22 09:27 | 12    | 553    | Equipment          |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 10/18/22 08:22 | 13    | 694    | Tree               |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 10/18/22 17:41 | 6     | 363    | Tree               |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 10/20/22 23:38 | 146   | 8,606  | Tree               |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 10/27/22 10:38 | 2     | 82     | Other              |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 11/10/22 10:45 | 1     | 64     | Unknown            |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 11/23/22 11:33 | 1     | 35     | AMI - No Job/Cause |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 11/24/22 16:23 | 1     | 5      | AMI - No Job/Cause |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 12/14/22 11:42 | 1     | 11     | Equipment          |
| 2A2 | SAIDI | 2 | SLOAN8524 | - |       | 12/26/22 17:52 | 1     | 5      | Unknown            |
| 2A3 | SAIDI | 3 | PROUD9475 | - |       | 01/07/22 12:00 | 1     | 9      | AMI - No Job/Cause |
| 2A3 | SAIDI | 3 | PROUD9475 | - |       | 01/11/22 16:32 | 1     | 9      | AMI - No Job/Cause |
| 2A3 | SAIDI | 3 | PROUD9475 | - |       | 01/18/22 15:46 | 1     | 20     | AMI - No Job/Cause |
| 2A3 | SAIDI | 3 | PROUD9475 | - |       | 01/28/22 15:00 | 73    | 13,680 | Equipment          |
| 2A3 | SAIDI | 3 | PROUD9475 | - |       | 03/19/22 21:58 | 4     | 709    | Animal             |
| 2A3 | SAIDI | 3 | PROUD9475 | - | Small | 04/14/22 14:11 | 1     | 113    | Other              |
| 2A3 | SAIDI | 3 | PROUD9475 | - | Small | 04/14/22 14:11 | 11    | 1,245  | Tree               |
| 2A3 | SAIDI | 3 | PROUD9475 | - | Small | 04/14/22 14:11 | 1     | 114    | Other              |
| 2A3 | SAIDI | 3 | PROUD9475 | - | Small | 04/14/22 14:11 | 1     | 113    | Wind               |
| 2A3 | SAIDI | 3 | PROUD9475 | - | Small | 04/14/22 14:11 | 4     | 453    | Other              |
| 2A3 | SAIDI | 3 | PROUD9475 | - | Small | 04/14/22 14:11 | 4     | 453    | Tree               |
| 2A3 | SAIDI | 3 | PROUD9475 | - | Small | 04/14/22 14:40 | 37    | 3,102  | Tree               |
| 2A3 | SAIDI | 3 | PROUD9475 | - | Small | 04/14/22 14:58 | 2     | 132    | Wind               |
| 2A3 | SAIDI | 3 | PROUD9475 | - | Small | 04/15/22 13:00 | 1     | 17     | AMI - No Job/Cause |

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|     |       |   |           |     |       |                |       |           |                    |
|-----|-------|---|-----------|-----|-------|----------------|-------|-----------|--------------------|
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 04/16/22 16:01 | 1     | 1,032     | AMI - No Job/Cause |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 05/06/22 05:43 | 1     | 1,980     | AMI - No Job/Cause |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 05/11/22 13:59 | 1     | 24        | Unknown            |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 05/11/22 13:59 | 2     | 49        | AMI - No Job/Cause |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 05/13/22 17:19 | 8     | 4,506     | Equipment          |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 05/17/22 17:57 | 63    | 10,497    | Animal             |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 05/30/22 07:53 | 63    | 3,573     | Tree               |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 05/30/22 07:53 | 1     | 57        | AMI - No Job/Cause |
| 2A3 | SAIDI | 3 | PROUD9475 | MED | Small | 06/01/22 19:59 | 9     | 1,273     | Equipment          |
| 2A3 | SAIDI | 3 | PROUD9475 | MED | Small | 06/01/22 19:59 | 1     | 141       | Unknown            |
| 2A3 | SAIDI | 3 | PROUD9475 | -   | Small | 06/03/22 08:07 | 1     | 306       | Animal             |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 06/06/22 08:23 | 1     | 96        | Equipment          |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 06/08/22 21:01 | 32    | 6,428     | Equipment          |
| 2A3 | SAIDI | 3 | PROUD9475 | -   | Small | 06/16/22 12:10 | 2     | 2,929     | AMI - No Job/Cause |
| 2A3 | SAIDI | 3 | PROUD9475 | -   | Small | 06/17/22 17:42 | 1     | 45        | Tree               |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 06/20/22 10:05 | 39    | 1,951     | AMI - No Job/Cause |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 06/25/22 09:25 | 1     | 395       | Unknown            |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 07/04/22 18:05 | 1     | 281       | AMI - No Job/Cause |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 07/04/22 18:05 | 1     | 281       | Unknown            |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 07/04/22 18:05 | 24    | 6,743     | Equipment          |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 07/11/22 06:29 | 62    | 13,499    | Other              |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 07/11/22 06:29 | 1     | 218       | AMI - No Job/Cause |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 07/18/22 17:05 | 1     | 545       | AMI - No Job/Cause |
| 2A3 | SAIDI | 3 | PROUD9475 | -   | Small | 07/20/22 14:35 | 3     | 211       | Tree               |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 07/22/22 10:42 | 15    | 8,472     | Equipment          |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 07/22/22 10:43 | 148   | 82,696    | Equipment          |
| 2A3 | SAIDI | 3 | PROUD9475 | MED | Small | 08/03/22 18:13 | 6     | 15,722    | Wind               |
| 2A3 | SAIDI | 3 | PROUD9475 | MED | Small | 08/03/22 19:29 | 2     | 5,386     | Tree               |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 08/06/22 07:19 | 56    | 4,032     | Tree               |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 08/06/22 07:20 | 1     | 72        | AMI - No Job/Cause |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 08/10/22 11:45 | 5     | 614       | Intentional        |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 08/19/22 02:37 | 1     | 161       | AMI - No Job/Cause |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 08/19/22 02:37 | 3     | 483       | Animal             |
| 2A3 | SAIDI | 3 | PROUD9475 | MED | Cat   | 08/29/22 17:45 | 11    | 18,915    | Wind               |
| 2A3 | SAIDI | 3 | PROUD9475 | MED | Cat   | 08/29/22 17:52 | 3,196 | 7,764,564 | Tree               |
| 2A3 | SAIDI | 3 | PROUD9475 | -   | Cat   | 08/31/22 20:27 | 1     | 2,277     | Unknown            |
| 2A3 | SAIDI | 3 | PROUD9475 | -   | Cat   | 08/31/22 20:28 | 1     | 2,277     | AMI - No Job/Cause |
| 2A3 | SAIDI | 3 | PROUD9475 | -   | Cat   | 09/01/22 10:13 | 1     | 6         | Unknown            |
| 2A3 | SAIDI | 3 | PROUD9475 | -   | Cat   | 09/01/22 22:19 | 45    | 32,956    | Tree               |
| 2A3 | SAIDI | 3 | PROUD9475 | -   | Cat   | 09/02/22 10:01 | 3     | 73        | Unknown            |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 09/08/22 10:31 | 1     | 528       | Tree               |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 09/08/22 21:42 | 1     | 14        | Other              |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 09/11/22 09:23 | 60    | 11,270    | Tree               |

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|-----|-------|---|-----------|-----|-------|----------------|-------|---------|---------------------|
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 09/16/22 08:27 | 165   | 89,714  | Equipment           |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 09/23/22 11:13 | 1     | 19      | Intentional         |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 10/06/22 13:42 | 1     | 114     | AMI - No Job/Cause  |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 10/06/22 13:42 | 16    | 1,823   | Public Interference |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 10/06/22 13:42 | 95    | 10,823  | Equipment           |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 10/19/22 22:08 | 1     | 128     | Other               |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 10/21/22 12:45 | 2     | 3,181   | Equipment           |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 10/31/22 23:55 | 1     | 49      | Unknown             |
| 2A3 | SAIDI | 3 | PROUD9475 | MED | Small | 11/05/22 19:39 | 1     | 219     | AMI - No Job/Cause  |
| 2A3 | SAIDI | 3 | PROUD9475 | -   | Small | 11/07/22 11:07 | 1     | 15      | Unknown             |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 11/23/22 04:59 | 1     | 307     | AMI - No Job/Cause  |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 11/27/22 16:23 | 1     | 209     | AMI - No Job/Cause  |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 12/11/22 11:45 | 1     | 9       | Tree                |
| 2A3 | SAIDI | 3 | PROUD9475 | -   |       | 12/31/22 03:01 | 2,113 | 358,604 | Tree                |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 01/02/22 23:11 | 100   | 25,716  | Equipment           |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 01/07/22 17:40 | 2     | 191     | AMI - No Job/Cause  |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 01/07/22 18:29 | 6     | 279     | AMI - No Job/Cause  |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 01/07/22 18:29 | 1     | 46      | Unknown             |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 02/16/22 21:32 | 3     | 400     | Other               |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 02/16/22 21:32 | 6     | 682     | Unknown             |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 02/16/22 21:32 | 1     | 110     | Other               |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 02/23/22 12:45 | 1     | 27      | Equipment           |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 02/24/22 15:36 | 1     | 8       | AMI - No Job/Cause  |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 02/28/22 11:53 | 5     | 178     | Intentional         |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 03/01/22 11:28 | 1     | 15      | AMI - No Job/Cause  |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 03/14/22 11:18 | 40    | 1,626   | Animal              |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 03/14/22 20:50 | 1     | 886     | Equipment           |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 03/20/22 09:09 | 1     | 114     | AMI - No Job/Cause  |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 03/26/22 14:53 | 1     | 6       | AMI - No Job/Cause  |
| 2A4 | SAIDI | 4 | AKRON9000 | -   | Small | 03/31/22 08:20 | 1     | 41      | AMI - No Job/Cause  |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 04/04/22 20:17 | 1     | 5       | AMI - No Job/Cause  |
| 2A4 | SAIDI | 4 | AKRON9000 | -   | Small | 04/14/22 14:26 | 1     | 98      | Wind                |
| 2A4 | SAIDI | 4 | AKRON9000 | -   | Small | 04/14/22 14:26 | 1     | 99      | AMI - No Job/Cause  |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 04/17/22 03:37 | 2     | 187     | Equipment           |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 04/17/22 03:37 | 1     | 93      | AMI - No Job/Cause  |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 05/16/22 09:10 | 8     | 2,180   | Tree                |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 05/31/22 01:38 | 1     | 464     | Tree                |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 05/31/22 22:50 | 2     | 10      | AMI - No Job/Cause  |
| 2A4 | SAIDI | 4 | AKRON9000 | -   | Small | 06/15/22 23:33 | 8     | 6,749   | Equipment           |
| 2A4 | SAIDI | 4 | AKRON9000 | -   | Small | 06/16/22 08:25 | 1     | 5       | AMI - No Job/Cause  |
| 2A4 | SAIDI | 4 | AKRON9000 | -   | Small | 06/17/22 13:19 | 2     | 10      | AMI - No Job/Cause  |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 06/28/22 23:57 | 30    | 4,036   | Tree                |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 06/28/22 23:57 | 38    | 5,073   | Equipment           |

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|-----|-------|---|-----------|-----|-------|----------------|-------|-----------|---------------------|
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 06/28/22 23:57 | 3     | 404       | Equipment           |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 06/28/22 23:57 | 5     | 673       | Equipment           |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 06/28/22 23:57 | 1     | 135       | Unknown             |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 06/28/22 23:57 | 1     | 135       | AMI - No Job/Cause  |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 07/01/22 09:21 | 76    | 6,222     | Animal              |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 07/01/22 15:04 | 1     | 6         | AMI - No Job/Cause  |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 07/14/22 20:37 | 2     | 975       | AMI - No Job/Cause  |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 07/30/22 13:51 | 36    | 5,244     | Equipment           |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 07/30/22 13:51 | 1     | 145       | Equipment           |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 07/30/22 13:51 | 2     | 291       | Other               |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 07/30/22 14:20 | 1     | 13        | AMI - No Job/Cause  |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 08/06/22 09:58 | 25    | 4,375     | Other               |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 08/06/22 09:58 | 3     | 528       | Equipment           |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 08/06/22 09:59 | 39    | 6,826     | Equipment           |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 08/06/22 09:59 | 30    | 5,250     | Other               |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 08/21/22 04:56 | 91    | 50,276    | Equipment           |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 08/21/22 13:18 | 222   | 11,333    | Equipment           |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 08/21/22 13:30 | 5     | 196       | Other               |
| 2A4 | SAIDI | 4 | AKRON9000 | MED | Cat   | 08/29/22 17:55 | 440   | 1,297,468 | Tree                |
| 2A4 | SAIDI | 4 | AKRON9000 | MED | Cat   | 08/29/22 17:56 | 257   | 777,819   | Tree                |
| 2A4 | SAIDI | 4 | AKRON9000 | MED | Cat   | 08/29/22 17:57 | 23    | 73,076    | Tree                |
| 2A4 | SAIDI | 4 | AKRON9000 | MED | Cat   | 08/29/22 17:57 | 2,102 | 4,495,311 | Tree                |
| 2A4 | SAIDI | 4 | AKRON9000 | MED | Cat   | 08/29/22 17:57 | 256   | 750,911   | Tree                |
| 2A4 | SAIDI | 4 | AKRON9000 | MED | Cat   | 08/29/22 17:58 | 1     | 1,252     | Wind                |
| 2A4 | SAIDI | 4 | AKRON9000 | MED | Cat   | 08/29/22 17:58 | 1     | 3,021     | Unknown             |
| 2A4 | SAIDI | 4 | AKRON9000 | MED | Cat   | 08/29/22 17:58 | 1     | 1,252     | Unknown             |
| 2A4 | SAIDI | 4 | AKRON9000 | MED | Cat   | 08/29/22 17:58 | 1     | 1,252     | Unknown             |
| 2A4 | SAIDI | 4 | AKRON9000 | -   | Cat   | 08/31/22 21:07 | 4     | 3,535     | Unknown             |
| 2A4 | SAIDI | 4 | AKRON9000 | -   | Cat   | 08/31/22 21:07 | 1     | 883       | Tree                |
| 2A4 | SAIDI | 4 | AKRON9000 | -   | Cat   | 08/31/22 21:07 | 2     | 1,767     | Other               |
| 2A4 | SAIDI | 4 | AKRON9000 | -   | Cat   | 08/31/22 21:07 | 1     | 883       | AMI - No Job/Cause  |
| 2A4 | SAIDI | 4 | AKRON9000 | -   | Cat   | 09/02/22 16:48 | 10    | 294       | Wind                |
| 2A4 | SAIDI | 4 | AKRON9000 | -   | Cat   | 09/02/22 20:45 | 2     | 60        | Other               |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 09/15/22 19:22 | 2     | 50        | Unknown             |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 09/15/22 19:22 | 3     | 74        | Unknown             |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 09/23/22 08:15 | 2     | 159       | AMI - No Job/Cause  |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 09/23/22 08:15 | 95    | 7,458     | Animal              |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 10/03/22 21:19 | 1     | 6         | Unknown             |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 10/05/22 04:18 | 70    | 47,941    | Tree                |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 10/07/22 07:57 | 1     | 588       | Equipment           |
| 2A4 | SAIDI | 4 | AKRON9000 | MED | Small | 11/05/22 19:24 | 1     | 987       | Tree                |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 11/23/22 09:52 | 44    | 5,346     | Public Interference |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 12/02/22 09:47 | 1     | 65        | Unknown             |

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|-----|-------|---|-----------|-----|-------|----------------|-----|-----------|--------------------|
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 12/02/22 09:47 | 2   | 131       | AMI - No Job/Cause |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 12/02/22 09:47 | 93  | 5,997     | Animal             |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 12/19/22 15:12 | 1   | 7         | AMI - No Job/Cause |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 12/19/22 23:59 | 5   | 271       | AMI - No Job/Cause |
| 2A4 | SAIDI | 4 | AKRON9000 | -   |       | 12/19/22 23:59 | 383 | 21,043    | Unknown            |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 01/05/22 22:53 | 1   | 238       | AMI - No Job/Cause |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 01/05/22 22:54 | 3   | 711       | Other              |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 01/09/22 10:19 | 91  | 6,866     | Equipment          |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 01/09/22 10:19 | 2   | 135       | AMI - No Job/Cause |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 02/03/22 11:29 | 1   | 13        | Unknown            |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 02/10/22 16:33 | 1   | 57        | AMI - No Job/Cause |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 02/11/22 13:27 | 1   | 43        | AMI - No Job/Cause |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 02/28/22 14:59 | 1   | 22        | Unknown            |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 02/28/22 15:17 | 2   | 19        | AMI - No Job/Cause |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 03/18/22 19:54 | 14  | 1,416     | Tree               |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 04/06/22 09:05 | 1   | 295       | AMI - No Job/Cause |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 04/09/22 13:06 | 1   | 24        | AMI - No Job/Cause |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 04/13/22 10:35 | 1   | 168       | AMI - No Job/Cause |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 04/28/22 09:37 | 1   | 122       | AMI - No Job/Cause |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 05/01/22 11:02 | 35  | 2,212     | Equipment          |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 05/04/22 12:01 | 1   | 88        | AMI - No Job/Cause |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 05/16/22 16:28 | 1   | 360       | Equipment          |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   | Small | 05/21/22 10:13 | 282 | 31,796    | Tree               |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 06/01/22 07:35 | 4   | 533       | Other              |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 06/01/22 07:35 | 22  | 2,928     | Equipment          |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 06/01/22 07:35 | 6   | 800       | Other              |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   | Small | 06/18/22 01:04 | 1   | 1,988     | AMI - No Job/Cause |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 07/05/22 04:57 | 28  | 9,612     | Equipment          |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 07/05/22 04:57 | 172 | 42,951    | Other              |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 07/12/22 08:07 | 1   | 364       | Animal             |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   | Small | 07/21/22 17:33 | 1   | 5         | Unknown            |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 07/24/22 20:46 | 129 | 19,915    | AMI - No Job/Cause |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 07/24/22 20:46 | 148 | 22,853    | Tree               |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 07/30/22 10:27 | 1   | 684       | AMI - No Job/Cause |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 07/30/22 10:27 | 6   | 4,106     | Equipment          |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 07/30/22 12:33 | 257 | 38,635    | Equipment          |
| 2A5 | SAIDI | 5 | LOMRD8516 | MED | Small | 08/03/22 18:29 | 1   | 3,227     | AMI - No Job/Cause |
| 2A5 | SAIDI | 5 | LOMRD8516 | MED | Small | 08/04/22 15:53 | 1   | 177       | Tree               |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 08/18/22 09:17 | 34  | 4,114     | Other              |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 08/19/22 05:06 | 1   | 952       | AMI - No Job/Cause |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |       | 08/21/22 04:48 | 1   | 537       | AMI - No Job/Cause |
| 2A5 | SAIDI | 5 | LOMRD8516 | MED | Cat   | 08/29/22 18:22 | 1   | 4,104     | AMI - No Job/Cause |
| 2A5 | SAIDI | 5 | LOMRD8516 | MED | Cat   | 08/29/22 18:22 | 269 | 1,103,885 | Other              |

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|     |       |   |           |     |     |                |       |           |                    |
|-----|-------|---|-----------|-----|-----|----------------|-------|-----------|--------------------|
| 2A5 | SAIDI | 5 | LOMRD8516 | MED | Cat | 08/29/22 18:22 | 1,370 | 5,623,476 | Tree               |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |     | 09/12/22 11:16 | 1     | 208       | AMI - No Job/Cause |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |     | 09/15/22 09:50 | 15    | 1,582     | Other              |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |     | 09/17/22 20:04 | 152   | 32,388    | Tree               |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |     | 09/18/22 10:41 | 8     | 240       | Equipment          |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |     | 10/03/22 08:23 | 1,705 | 421,544   | Tree               |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |     | 10/03/22 15:45 | 1     | 53        | AMI - No Job/Cause |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |     | 10/10/22 13:52 | 10    | 722       | Equipment          |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |     | 10/28/22 15:03 | 1     | 22        | Other              |
| 2A5 | SAIDI | 5 | LOMRD8516 | -   |     | 11/18/22 09:23 | 1     | 10        | Unknown            |



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A number of outages for the circuits in Appendix 2B were recorded by AMI meters but could not be associated with an InService OMS event using current algorithms. As a result, no cause can be directly attributed to these events. However, these unassociated AMI meter outages account for only 5.3% of the customers interrupted and 6.1% of the customer-minutes interrupted for these circuits.

**Appendix 2B**  
**Outage and Cause Listing - SAIDI - Circuit Basis**

| Ref# | Metric | Rank | Circuit   | MED | Storm | Interruption Date/Time | Customers Interrupted | Customer Minutes Interrupted | Cause               |
|------|--------|------|-----------|-----|-------|------------------------|-----------------------|------------------------------|---------------------|
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   |       | 01/06/22 09:29         | 1                     | 567                          | AMI - No Job/Cause  |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   |       | 01/06/22 09:29         | 1                     | 567                          | Equipment           |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   |       | 01/06/22 09:29         | 4                     | 2,269                        | Public Interference |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   |       | 01/12/22 09:10         | 1                     | 111                          | AMI - No Job/Cause  |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   |       | 02/23/22 00:11         | 2                     | 1,107                        | Wind                |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   |       | 04/02/22 09:50         | 1                     | 174                          | AMI - No Job/Cause  |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   |       | 04/11/22 16:53         | 1                     | 6                            | Tree                |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   |       | 04/21/22 13:00         | 1                     | 114                          | Intentional         |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   |       | 04/21/22 13:00         | 1                     | 96                           | AMI - No Job/Cause  |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   |       | 04/23/22 10:42         | 1                     | 34                           | Intentional         |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   |       | 04/23/22 12:45         | 5                     | 321                          | Intentional         |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   |       | 04/26/22 12:21         | 1                     | 40                           | Other               |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   |       | 05/31/22 15:56         | 1                     | 7                            | AMI - No Job/Cause  |
| 2B1  | SAIDI  | 1    | LYNCH2260 | MED | Small | 06/01/22 12:28         | 1                     | 57                           | AMI - No Job/Cause  |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   | Small | 06/03/22 18:09         | 1                     | 40                           | Unknown             |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   | Small | 06/19/22 20:15         | 1                     | 40                           | AMI - No Job/Cause  |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   |       | 07/17/22 11:31         | 1                     | 5                            | Unknown             |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   | Small | 07/20/22 18:41         | 1                     | 6                            | Unknown             |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   | Small | 07/20/22 18:42         | 2                     | 13                           | AMI - No Job/Cause  |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   | Small | 07/21/22 00:39         | 1                     | 192                          | Unknown             |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   | Small | 07/21/22 05:40         | 1                     | 6                            | AMI - No Job/Cause  |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   | Small | 07/21/22 07:46         | 11                    | 1,019                        | Tree                |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   | Small | 07/21/22 09:16         | 4                     | 659                          | Tree                |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   |       | 07/23/22 12:35         | 1                     | 34                           | AMI - No Job/Cause  |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   |       | 08/06/22 19:01         | 1                     | 29                           | Unknown             |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   |       | 08/06/22 19:01         | 1                     | 911                          | AMI - No Job/Cause  |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   |       | 08/06/22 19:45         | 34                    | 1,059                        | Equipment           |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   |       | 08/06/22 22:19         | 1                     | 33                           | Unknown             |
| 2B1  | SAIDI  | 1    | LYNCH2260 | -   |       | 08/06/22 22:21         | 1                     | 31                           | AMI - No Job/Cause  |
| 2B1  | SAIDI  | 1    | LYNCH2260 | MED | Cat   | 08/29/22 18:37         | 2                     | 13                           | Wind                |
| 2B1  | SAIDI  | 1    | LYNCH2260 | MED | Cat   | 08/30/22 10:00         | 685                   | 1,200,241                    | Tree                |

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|-----|-------|---|-----------|-----|-------|----------------|----|--------|--------------------|
| 2B1 | SAIDI | 1 | LYNCH2260 | MED | Cat   | 08/30/22 10:14 | 1  | 1,828  | Equipment          |
| 2B1 | SAIDI | 1 | LYNCH2260 | MED | Cat   | 08/30/22 10:15 | 1  | 1,819  | Wind               |
| 2B1 | SAIDI | 1 | LYNCH2260 | MED | Cat   | 08/30/22 10:15 | 1  | 1,819  | Wind               |
| 2B1 | SAIDI | 1 | LYNCH2260 | MED | Cat   | 08/30/22 10:15 | 19 | 34,706 | Tree               |
| 2B1 | SAIDI | 1 | LYNCH2260 | MED | Cat   | 08/30/22 10:15 | 1  | 1,819  | Wind               |
| 2B1 | SAIDI | 1 | LYNCH2260 | MED | Cat   | 08/30/22 10:15 | 4  | 7,279  | AMI - No Job/Cause |
| 2B1 | SAIDI | 1 | LYNCH2260 | MED | Cat   | 08/30/22 10:15 | 1  | 1,820  | Unknown            |
| 2B1 | SAIDI | 1 | LYNCH2260 | MED | Cat   | 08/30/22 10:16 | 1  | 1,820  | Unknown            |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   | Cat   | 08/31/22 17:46 | 8  | 98     | Tree               |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   | Cat   | 08/31/22 18:16 | 1  | 615    | Unknown            |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   | Cat   | 08/31/22 18:16 | 6  | 3,691  | AMI - No Job/Cause |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   | Cat   | 08/31/22 18:16 | 1  | 615    | Other              |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   | Cat   | 09/01/22 09:34 | 5  | 74     | Equipment          |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   | Cat   | 09/01/22 10:56 | 1  | 8      | Unknown            |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   | Cat   | 09/01/22 10:56 | 3  | 24     | AMI - No Job/Cause |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   | Cat   | 09/02/22 20:18 | 7  | 7,407  | Unknown            |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   |       | 09/18/22 08:35 | 1  | 73     | AMI - No Job/Cause |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   |       | 09/19/22 12:12 | 9  | 64     | Tree               |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   |       | 09/26/22 10:27 | 2  | 26     | AMI - No Job/Cause |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   |       | 09/29/22 17:23 | 1  | 44     | AMI - No Job/Cause |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   |       | 09/29/22 17:23 | 1  | 44     | Equipment          |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   |       | 10/02/22 13:13 | 1  | 52     | AMI - No Job/Cause |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   |       | 10/19/22 20:02 | 5  | 805    | Tree               |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   |       | 11/18/22 17:42 | 1  | 14     | Unknown            |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   |       | 11/25/22 16:35 | 2  | 36     | Tree               |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   |       | 11/30/22 17:11 | 1  | 37     | Wind               |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   |       | 11/30/22 17:12 | 1  | 37     | AMI - No Job/Cause |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   |       | 12/15/22 13:37 | 4  | 377    | Tree               |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   |       | 12/15/22 16:18 | 1  | 13     | Wind               |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   |       | 12/15/22 18:10 | 2  | 21     | Unknown            |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   |       | 12/20/22 17:07 | 1  | 34     | AMI - No Job/Cause |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   | Small | 12/23/22 21:32 | 1  | 716    | Wind               |
| 2B1 | SAIDI | 1 | LYNCH2260 | -   |       | 12/26/22 13:37 | 1  | 13     | AMI - No Job/Cause |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 01/07/22 10:19 | 20 | 1,831  | Tree               |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 01/07/22 10:19 | 10 | 915    | Tree               |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 01/07/22 10:19 | 1  | 92     | Tree               |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 01/29/22 16:45 | 1  | 55     | AMI - No Job/Cause |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 02/14/22 16:58 | 1  | 8      | Tree               |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 02/18/22 13:48 | 1  | 64     | Tree               |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 02/18/22 14:19 | 3  | 199    | AMI - No Job/Cause |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 02/23/22 17:32 | 33 | 977    | Tree               |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 04/05/22 09:38 | 1  | 36     | Tree               |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 04/07/22 13:12 | 1  | 1,616  | AMI - No Job/Cause |

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|-----|-------|---|-----------|-----|-------|----------------|-----|-----------|---------------------|
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 04/12/22 23:25 | 4   | 194       | AMI - No Job/Cause  |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 04/23/22 13:17 | 1   | 25        | Unknown             |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 05/04/22 21:11 | 1   | 10        | AMI - No Job/Cause  |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 05/04/22 22:20 | 1   | 194       | AMI - No Job/Cause  |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 05/10/22 05:58 | 1   | 921       | AMI - No Job/Cause  |
| 2B2 | SAIDI | 2 | EVRGN2166 | MED | Small | 06/01/22 12:41 | 909 | 1,623,838 | Tree                |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   | Small | 06/03/22 11:47 | 39  | 410       | Unknown             |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   | Small | 06/03/22 16:19 | 1   | 283       | AMI - No Job/Cause  |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 06/06/22 00:21 | 1   | 571       | AMI - No Job/Cause  |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   | Small | 06/19/22 18:05 | 4   | 434       | AMI - No Job/Cause  |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 07/12/22 13:09 | 1   | 11        | Unknown             |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 07/16/22 08:14 | 1   | 547       | AMI - No Job/Cause  |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 07/24/22 22:18 | 1   | 141       | Equipment           |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 07/24/22 22:18 | 1   | 140       | AMI - No Job/Cause  |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 07/24/22 22:18 | 376 | 54,165    | Equipment           |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 07/24/22 22:18 | 555 | 79,159    | Equipment           |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 07/25/22 13:40 | 1   | 23        | Tree                |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 07/25/22 20:00 | 2   | 252       | AMI - No Job/Cause  |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 07/25/22 20:01 | 85  | 10,601    | Public Interference |
| 2B2 | SAIDI | 2 | EVRGN2166 | MED | Small | 08/04/22 11:49 | 1   | 422       | Tree                |
| 2B2 | SAIDI | 2 | EVRGN2166 | MED | Small | 08/04/22 11:49 | 26  | 10,968    | Tree                |
| 2B2 | SAIDI | 2 | EVRGN2166 | MED | Small | 08/04/22 11:49 | 18  | 7,592     | Tree                |
| 2B2 | SAIDI | 2 | EVRGN2166 | MED | Small | 08/04/22 11:49 | 5   | 2,109     | Tree                |
| 2B2 | SAIDI | 2 | EVRGN2166 | MED | Small | 08/04/22 11:49 | 1   | 422       | Unknown             |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   | Small | 08/04/22 22:30 | 1   | 1,079     | Tree                |
| 2B2 | SAIDI | 2 | EVRGN2166 | MED | Cat   | 08/29/22 20:39 | 905 | 3,656,081 | Tree                |
| 2B2 | SAIDI | 2 | EVRGN2166 | MED | Cat   | 08/29/22 20:40 | 1   | 4,037     | Tree                |
| 2B2 | SAIDI | 2 | EVRGN2166 | MED | Cat   | 08/29/22 20:40 | 5   | 20,185    | Tree                |
| 2B2 | SAIDI | 2 | EVRGN2166 | MED | Cat   | 08/29/22 20:40 | 1   | 4,037     | Unknown             |
| 2B2 | SAIDI | 2 | EVRGN2166 | MED | Cat   | 08/29/22 20:40 | 2   | 8,073     | AMI - No Job/Cause  |
| 2B2 | SAIDI | 2 | EVRGN2166 | MED | Cat   | 08/29/22 20:40 | 1   | 4,037     | Tree                |
| 2B2 | SAIDI | 2 | EVRGN2166 | MED | Cat   | 08/29/22 20:40 | 2   | 8,074     | Unknown             |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   | Cat   | 09/03/22 17:46 | 1   | 1,031     | Unknown             |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 09/06/22 04:37 | 1   | 30        | AMI - No Job/Cause  |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 09/06/22 19:28 | 1   | 11        | AMI - No Job/Cause  |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 09/07/22 00:59 | 1   | 2,008     | AMI - No Job/Cause  |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 09/09/22 19:39 | 1   | 169       | AMI - No Job/Cause  |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 09/12/22 05:32 | 1   | 188       | AMI - No Job/Cause  |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 09/12/22 09:11 | 1   | 692       | AMI - No Job/Cause  |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 09/27/22 05:38 | 1   | 7         | AMI - No Job/Cause  |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 09/27/22 13:02 | 1   | 123       | AMI - No Job/Cause  |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 09/29/22 09:45 | 13  | 514       | Unknown             |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 10/24/22 05:52 | 1   | 7         | AMI - No Job/Cause  |

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|-----|-------|---|-----------|-----|-------|----------------|----|--------|--------------------|
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 10/24/22 10:25 | 4  | 227    | AMI - No Job/Cause |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 10/24/22 10:25 | 1  | 48     | Unknown            |
| 2B2 | SAIDI | 2 | EVRGN2166 | MED | Small | 11/05/22 19:54 | 1  | 1,180  | Tree               |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 12/03/22 14:48 | 50 | 1,961  | Wind               |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 12/10/22 09:06 | 1  | 333    | Tree               |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 12/14/22 15:43 | 1  | 26     | Unknown            |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 12/14/22 20:38 | 49 | 18,022 | Tree               |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 12/14/22 22:17 | 1  | 21     | AMI - No Job/Cause |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 12/15/22 02:58 | 49 | 2,389  | Tree               |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 12/31/22 09:31 | 1  | 9      | AMI - No Job/Cause |
| 2B2 | SAIDI | 2 | EVRGN2166 | -   |       | 12/31/22 10:14 | 1  | 38     | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 01/09/22 12:27 | 2  | 263    | Unknown            |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 01/26/22 09:53 | 2  | 174    | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 03/21/22 07:43 | 1  | 7      | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Small | 03/31/22 08:24 | 1  | 200    | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Small | 03/31/22 09:17 | 1  | 7,217  | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Small | 03/31/22 10:36 | 1  | 5      | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 04/02/22 08:35 | 1  | 25     | Tree               |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Small | 04/15/22 19:04 | 1  | 32     | Tree               |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 04/18/22 17:34 | 2  | 31     | Unknown            |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 04/22/22 11:43 | 1  | 8      | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 04/28/22 13:52 | 1  | 34     | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 04/30/22 10:23 | 1  | 46     | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 04/30/22 10:24 | 1  | 47     | Intentional        |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 04/30/22 11:41 | 7  | 363    | Intentional        |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 04/30/22 11:41 | 3  | 155    | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 05/01/22 07:28 | 3  | 465    | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 05/01/22 10:30 | 1  | 141    | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 05/02/22 13:32 | 1  | 38     | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 05/04/22 09:28 | 2  | 60     | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 05/04/22 12:23 | 1  | 131    | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 05/05/22 09:57 | 2  | 355    | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 05/05/22 10:45 | 1  | 47     | Intentional        |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 05/05/22 15:21 | 2  | 38     | Unknown            |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 05/07/22 10:05 | 1  | 259    | Intentional        |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 05/07/22 10:06 | 1  | 261    | Intentional        |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 05/07/22 10:52 | 1  | 22     | Intentional        |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 05/07/22 13:22 | 3  | 292    | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 05/07/22 13:31 | 11 | 1,311  | Intentional        |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 05/09/22 09:22 | 23 | 1,953  | Other              |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 05/09/22 09:22 | 1  | 85     | Intentional        |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 05/09/22 10:17 | 1  | 84     | Unknown            |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 05/09/22 12:20 | 2  | 88     | Intentional        |

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|     |       |   |           |     |       |                |     |           |                    |
|-----|-------|---|-----------|-----|-------|----------------|-----|-----------|--------------------|
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 05/15/22 08:33 | 2   | 176       | Intentional        |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 05/15/22 08:33 | 1   | 88        | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Small | 05/22/22 10:07 | 1   | 72        | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | MED | Small | 06/01/22 12:46 | 496 | 139,988   | Equipment          |
| 2B3 | SAIDI | 3 | MEYRS1691 | MED | Small | 06/01/22 12:51 | 1   | 2,719     | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | MED | Small | 06/02/22 00:21 | 1   | 94        | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | MED | Small | 06/02/22 01:23 | 1   | 32        | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | MED | Small | 06/02/22 06:13 | 1   | 241       | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | MED | Small | 06/02/22 06:20 | 1   | 235       | Equipment          |
| 2B3 | SAIDI | 3 | MEYRS1691 | MED | Small | 06/02/22 11:07 | 2   | 169       | Unknown            |
| 2B3 | SAIDI | 3 | MEYRS1691 | MED | Small | 06/02/22 11:07 | 1   | 85        | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Small | 06/02/22 15:30 | 1   | 19        | Unknown            |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Small | 06/02/22 15:30 | 1   | 19        | Unknown            |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Small | 06/02/22 15:30 | 4   | 75        | Equipment          |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Small | 06/02/22 15:30 | 1   | 19        | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Small | 06/02/22 16:22 | 1   | 32        | Tree               |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Small | 06/02/22 16:22 | 1   | 32        | Equipment          |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Small | 06/02/22 16:22 | 1   | 32        | Equipment          |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Small | 06/02/22 16:22 | 1   | 32        | Tree               |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Small | 06/02/22 16:22 | 11  | 347       | Equipment          |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Small | 06/03/22 11:04 | 1   | 104       | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Small | 06/03/22 13:59 | 1   | 6         | Unknown            |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Small | 06/03/22 15:29 | 1   | 8         | Unknown            |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Small | 06/03/22 15:38 | 1   | 171       | Tree               |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 06/15/22 09:53 | 1   | 17        | Equipment          |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 07/03/22 19:35 | 1   | 8         | Unknown            |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 07/05/22 20:52 | 3   | 1,117     | Tree               |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 07/18/22 13:08 | 1   | 23        | Tree               |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 08/06/22 02:27 | 1   | 680       | Tree               |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 08/11/22 13:44 | 1   | 6         | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 08/25/22 19:46 | 1   | 7         | Tree               |
| 2B3 | SAIDI | 3 | MEYRS1691 | MED | Cat   | 08/29/22 18:03 | 1   | 7,227     | Equipment          |
| 2B3 | SAIDI | 3 | MEYRS1691 | MED | Cat   | 08/29/22 18:04 | 1   | 5,748     | Tree               |
| 2B3 | SAIDI | 3 | MEYRS1691 | MED | Cat   | 08/29/22 18:06 | 16  | 91,741    | Other              |
| 2B3 | SAIDI | 3 | MEYRS1691 | MED | Cat   | 08/29/22 18:07 | 125 | 714,643   | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | MED | Cat   | 08/29/22 18:08 | 532 | 3,043,055 | Tree               |
| 2B3 | SAIDI | 3 | MEYRS1691 | MED | Cat   | 08/29/22 18:08 | 6   | 34,345    | Other              |
| 2B3 | SAIDI | 3 | MEYRS1691 | MED | Cat   | 08/29/22 18:08 | 1   | 5,724     | Unknown            |
| 2B3 | SAIDI | 3 | MEYRS1691 | MED | Cat   | 08/29/22 18:08 | 1   | 5,724     | Wind               |
| 2B3 | SAIDI | 3 | MEYRS1691 | MED | Cat   | 08/29/22 18:08 | 2   | 11,449    | Unknown            |
| 2B3 | SAIDI | 3 | MEYRS1691 | MED | Cat   | 08/29/22 18:08 | 1   | 5,724     | Wind               |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Cat   | 09/02/22 09:11 | 1   | 53        | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Cat   | 09/02/22 18:12 | 1   | 35        | Wind               |

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|     |       |   |           |     |       |                |     |         |                    |
|-----|-------|---|-----------|-----|-------|----------------|-----|---------|--------------------|
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Cat   | 09/03/22 03:30 | 2   | 296     | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Cat   | 09/03/22 05:30 | 3   | 96      | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Cat   | 09/03/22 08:22 | 32  | 217     | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   | Cat   | 09/03/22 08:22 | 1   | 7       | Wind               |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 09/04/22 18:23 | 1   | 10      | Unknown            |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 09/04/22 18:38 | 1   | 27      | Unknown            |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 09/06/22 16:16 | 1   | 65      | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 09/19/22 12:33 | 1   | 9       | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 09/21/22 15:17 | 1   | 94      | Unknown            |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 09/24/22 09:47 | 1   | 6       | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 09/30/22 11:53 | 2   | 13      | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 10/05/22 11:52 | 1   | 10      | Tree               |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 10/18/22 15:36 | 1   | 6       | Unknown            |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 11/03/22 11:25 | 12  | 863     | Tree               |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 11/03/22 11:25 | 2   | 144     | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | MED | Small | 11/05/22 19:31 | 16  | 38,923  | Wind               |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 11/20/22 16:46 | 1   | 6       | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 11/25/22 09:58 | 1   | 8       | AMI - No Job/Cause |
| 2B3 | SAIDI | 3 | MEYRS1691 | -   |       | 11/30/22 16:59 | 2   | 318     | Tree               |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 01/09/22 16:48 | 1   | 60      | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 02/06/22 13:00 | 1   | 7       | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 02/16/22 11:46 | 1   | 217     | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 02/19/22 11:44 | 1   | 24      | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 02/20/22 11:45 | 1   | 8       | Unknown            |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 04/03/22 09:38 | 1   | 29      | Unknown            |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 04/08/22 18:40 | 1   | 51      | Tree               |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 04/13/22 07:12 | 1   | 180     | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 04/30/22 16:23 | 1   | 5       | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 05/11/22 01:24 | 1   | 1,032   | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   | Small | 05/22/22 03:46 | 1   | 13      | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 05/22/22 22:26 | 1   | 1,339   | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | MED | Small | 06/01/22 12:41 | 1   | 431     | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | MED | Small | 06/01/22 12:41 | 511 | 512,203 | Tree               |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   | Small | 06/03/22 10:34 | 19  | 2,611   | Tree               |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   | Small | 06/03/22 11:24 | 1   | 75      | Tree               |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   | Small | 06/03/22 11:29 | 3   | 210     | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 06/07/22 11:54 | 12  | 2,003   | Unknown            |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 06/08/22 23:00 | 1   | 13      | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 06/09/22 20:28 | 1   | 312     | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   | Small | 06/15/22 14:17 | 1   | 19      | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   | Small | 06/15/22 16:27 | 1   | 823     | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 06/25/22 12:55 | 1   | 319     | Equipment          |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 07/08/22 17:46 | 1   | 22      | AMI - No Job/Cause |

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|     |       |   |           |     |       |                |     |           |                    |
|-----|-------|---|-----------|-----|-------|----------------|-----|-----------|--------------------|
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 07/12/22 16:21 | 1   | 22        | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   | Small | 07/21/22 16:28 | 7   | 386       | Unknown            |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   | Small | 07/21/22 16:28 | 1   | 55        | Intentional        |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 07/24/22 22:18 | 1   | 140       | Equipment          |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 07/27/22 11:07 | 1   | 6         | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 07/29/22 19:09 | 15  | 927       | Tree               |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 07/29/22 19:09 | 1   | 62        | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 07/30/22 08:52 | 7   | 1,595     | Tree               |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   | Small | 08/04/22 22:30 | 1   | 1,079     | Tree               |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   | Small | 08/04/22 22:30 | 37  | 39,904    | Equipment          |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   | Small | 08/05/22 03:38 | 598 | 406,912   | Tree               |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   | Small | 08/05/22 16:14 | 66  | 949       | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   | Small | 08/05/22 16:14 | 1   | 14        | Tree               |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 08/13/22 04:08 | 1   | 608       | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 08/14/22 11:51 | 1   | 372       | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 08/16/22 12:03 | 5   | 200       | Tree               |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 08/16/22 12:03 | 16  | 640       | Tree               |
| 2B4 | SAIDI | 4 | EVRGN1766 | MED | Cat   | 08/29/22 18:02 | 2   | 8,359     | Unknown            |
| 2B4 | SAIDI | 4 | EVRGN1766 | MED | Cat   | 08/29/22 18:02 | 107 | 447,328   | Wind               |
| 2B4 | SAIDI | 4 | EVRGN1766 | MED | Cat   | 08/29/22 18:02 | 471 | 1,974,659 | Wind               |
| 2B4 | SAIDI | 4 | EVRGN1766 | MED | Cat   | 08/29/22 18:02 | 1   | 4,179     | Tree               |
| 2B4 | SAIDI | 4 | EVRGN1766 | MED | Cat   | 08/29/22 18:02 | 3   | 12,538    | Other              |
| 2B4 | SAIDI | 4 | EVRGN1766 | MED | Cat   | 08/29/22 18:02 | 1   | 4,179     | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | MED | Cat   | 08/29/22 18:02 | 1   | 4,179     | Wind               |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   | Cat   | 09/01/22 15:53 | 4   | 155       | Wind               |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   | Cat   | 09/01/22 16:01 | 6   | 1,142     | Wind               |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   | Cat   | 09/03/22 15:52 | 1   | 15        | Unknown            |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 10/12/22 21:25 | 1   | 24        | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 10/13/22 11:25 | 1   | 34        | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 10/17/22 09:39 | 1   | 1,525     | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 10/19/22 20:19 | 2   | 65        | Tree               |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 10/30/22 14:14 | 1   | 7         | Unknown            |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 10/30/22 16:53 | 1   | 10        | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 10/30/22 16:53 | 1   | 11        | Unknown            |
| 2B4 | SAIDI | 4 | EVRGN1766 | MED | Small | 11/05/22 12:23 | 1   | 7         | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 11/15/22 09:45 | 1   | 94        | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 12/09/22 13:06 | 1   | 9         | AMI - No Job/Cause |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 12/12/22 09:57 | 10  | 447       | Intentional        |
| 2B4 | SAIDI | 4 | EVRGN1766 | -   |       | 12/29/22 13:44 | 1   | 40        | Tree               |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 01/16/22 09:54 | 1   | 18        | Unknown            |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 02/01/22 09:00 | 1   | 168       | AMI - No Job/Cause |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 02/02/22 11:15 | 1   | 22        | Other              |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 02/02/22 11:16 | 1   | 22        | Other              |

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|     |       |   |           |   |       |                |     |        |                    |
|-----|-------|---|-----------|---|-------|----------------|-----|--------|--------------------|
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 02/07/22 15:45 | 1   | 7      | AMI - No Job/Cause |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 02/12/22 11:39 | 1   | 108    | AMI - No Job/Cause |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 02/18/22 22:30 | 1   | 125    | Other              |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 02/18/22 22:30 | 1   | 125    | Other              |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 02/18/22 22:31 | 6   | 748    | Other              |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 02/18/22 22:31 | 641 | 79,829 | Tree               |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 02/18/22 22:31 | 1   | 125    | Other              |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 02/18/22 22:31 | 1   | 125    | Other              |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 02/18/22 22:31 | 49  | 6,104  | Other              |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 02/18/22 22:31 | 1   | 125    | Other              |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 02/18/22 22:31 | 1   | 125    | Other              |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 02/18/22 22:31 | 1   | 125    | Other              |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 02/18/22 22:31 | 1   | 124    | Other              |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 02/18/22 22:31 | 1   | 124    | Unknown            |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 02/22/22 05:35 | 1   | 312    | Tree               |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 03/01/22 08:04 | 1   | 374    | AMI - No Job/Cause |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 03/03/22 11:13 | 2   | 167    | Animal             |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 03/09/22 10:17 | 1   | 46     | AMI - No Job/Cause |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 03/11/22 11:06 | 1   | 47     | Intentional        |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 03/14/22 14:52 | 1   | 62     | AMI - No Job/Cause |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 03/23/22 17:39 | 1   | 85     | Unknown            |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 03/23/22 17:39 | 1   | 5      | AMI - No Job/Cause |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 03/27/22 12:32 | 1   | 26     | Unknown            |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 03/29/22 11:46 | 1   | 7      | AMI - No Job/Cause |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 04/05/22 10:18 | 1   | 107    | AMI - No Job/Cause |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 04/07/22 09:59 | 1   | 9      | AMI - No Job/Cause |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 04/11/22 13:02 | 1   | 6      | AMI - No Job/Cause |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 04/19/22 12:12 | 1   | 8      | Unknown            |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 04/21/22 12:02 | 16  | 2,207  | Equipment          |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 04/27/22 09:39 | 1   | 31     | Intentional        |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 05/08/22 09:05 | 1   | 602    | Equipment          |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 05/13/22 15:31 | 67  | 5,716  | Equipment          |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 05/13/22 15:31 | 2   | 171    | Equipment          |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 05/15/22 09:51 | 2   | 560    | Equipment          |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 05/16/22 09:43 | 1   | 173    | AMI - No Job/Cause |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 05/25/22 21:58 | 1   | 145    | Tree               |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 06/07/22 04:04 | 1   | 474    | Equipment          |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 06/14/22 00:56 | 1   | 713    | Unknown            |
| 2B5 | SAIDI | 5 | MADRD9933 | - |       | 06/14/22 09:29 | 1   | 271    | Tree               |
| 2B5 | SAIDI | 5 | MADRD9933 | - | Small | 06/16/22 08:32 | 1   | 1,101  | Equipment          |
| 2B5 | SAIDI | 5 | MADRD9933 | - | Small | 06/16/22 13:05 | 1   | 277    | Wind               |
| 2B5 | SAIDI | 5 | MADRD9933 | - | Small | 06/16/22 13:05 | 1   | 277    | AMI - No Job/Cause |
| 2B5 | SAIDI | 5 | MADRD9933 | - | Small | 06/18/22 10:38 | 1   | 166    | Tree               |



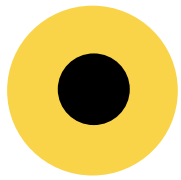
Reliability Performance and Power Quality Resolution Process  
DTE Electric Report for 2022

|     |       |   |           |     |       |                |     |           |                    |
|-----|-------|---|-----------|-----|-------|----------------|-----|-----------|--------------------|
| 2B5 | SAIDI | 5 | MADRD9933 | -   | Small | 06/18/22 10:38 | 1   | 174       | AMI - No Job/Cause |
| 2B5 | SAIDI | 5 | MADRD9933 | -   | Small | 06/18/22 10:38 | 1   | 166       | Wind               |
| 2B5 | SAIDI | 5 | MADRD9933 | -   | Small | 06/18/22 10:38 | 118 | 20,118    | Tree               |
| 2B5 | SAIDI | 5 | MADRD9933 | -   | Small | 06/18/22 10:38 | 22  | 3,734     | Wind               |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 06/24/22 10:24 | 1   | 335       | Equipment          |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 07/08/22 16:15 | 1   | 177       | Equipment          |
| 2B5 | SAIDI | 5 | MADRD9933 | -   | Small | 07/22/22 02:36 | 40  | 19,122    | Tree               |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 07/24/22 04:36 | 1   | 152       | Wind               |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 07/24/22 05:34 | 1   | 422       | Unknown            |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 07/24/22 06:10 | 1   | 352       | Unknown            |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 07/24/22 06:10 | 1   | 599       | Lightning          |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 07/24/22 11:41 | 1   | 347       | Equipment          |
| 2B5 | SAIDI | 5 | MADRD9933 | MED | Small | 08/03/22 16:50 | 1   | 169       | Wind               |
| 2B5 | SAIDI | 5 | MADRD9933 | MED | Small | 08/03/22 16:50 | 7   | 1,183     | Wind               |
| 2B5 | SAIDI | 5 | MADRD9933 | MED | Small | 08/03/22 16:50 | 1   | 169       | Wind               |
| 2B5 | SAIDI | 5 | MADRD9933 | -   | Small | 08/05/22 06:23 | 1   | 416       | AMI - No Job/Cause |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 08/06/22 02:56 | 30  | 14,306    | Equipment          |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 08/06/22 02:56 | 32  | 15,258    | AMI - No Job/Cause |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 08/06/22 02:56 | 12  | 8,896     | Tree               |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 08/06/22 11:59 | 13  | 1,450     | Equipment          |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 08/12/22 17:08 | 1   | 115       | Animal             |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 08/17/22 11:41 | 1   | 57        | AMI - No Job/Cause |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 08/24/22 14:31 | 1   | 7         | AMI - No Job/Cause |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 08/25/22 14:21 | 1   | 10        | Intentional        |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 08/26/22 09:41 | 1   | 19        | AMI - No Job/Cause |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 08/26/22 12:58 | 2   | 81        | Equipment          |
| 2B5 | SAIDI | 5 | MADRD9933 | MED | Cat   | 08/29/22 17:16 | 1   | 6,913     | Tree               |
| 2B5 | SAIDI | 5 | MADRD9933 | MED | Cat   | 08/29/22 17:16 | 1   | 5,982     | Unknown            |
| 2B5 | SAIDI | 5 | MADRD9933 | MED | Cat   | 08/29/22 17:16 | 119 | 714,341   | Tree               |
| 2B5 | SAIDI | 5 | MADRD9933 | MED | Cat   | 08/29/22 17:16 | 1   | 7,348     | Tree               |
| 2B5 | SAIDI | 5 | MADRD9933 | MED | Cat   | 08/29/22 17:16 | 1   | 8,463     | Tree               |
| 2B5 | SAIDI | 5 | MADRD9933 | MED | Cat   | 08/29/22 17:16 | 1   | 3,360     | Tree               |
| 2B5 | SAIDI | 5 | MADRD9933 | MED | Cat   | 08/29/22 17:16 | 54  | 249,440   | Tree               |
| 2B5 | SAIDI | 5 | MADRD9933 | MED | Cat   | 08/29/22 17:17 | 242 | 1,312,912 | Tree               |
| 2B5 | SAIDI | 5 | MADRD9933 | MED | Cat   | 08/29/22 17:17 | 9   | 63,953    | Tree               |
| 2B5 | SAIDI | 5 | MADRD9933 | MED | Cat   | 08/29/22 17:17 | 1   | 5,346     | Wind               |
| 2B5 | SAIDI | 5 | MADRD9933 | MED | Cat   | 08/29/22 17:17 | 79  | 332,776   | AMI - No Job/Cause |
| 2B5 | SAIDI | 5 | MADRD9933 | MED | Cat   | 08/29/22 17:17 | 286 | 1,032,221 | Wind               |
| 2B5 | SAIDI | 5 | MADRD9933 | -   | Cat   | 09/01/22 01:51 | 1   | 3,906     | Wind               |
| 2B5 | SAIDI | 5 | MADRD9933 | -   | Cat   | 09/01/22 07:36 | 1   | 2,388     | Unknown            |
| 2B5 | SAIDI | 5 | MADRD9933 | -   | Cat   | 09/01/22 07:36 | 17  | 40,594    | Tree               |
| 2B5 | SAIDI | 5 | MADRD9933 | -   | Cat   | 09/02/22 10:04 | 5   | 560       | Wind               |
| 2B5 | SAIDI | 5 | MADRD9933 | -   | Cat   | 09/02/22 16:17 | 1   | 7         | Tree               |

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|     |       |   |           |     |       |                |     |         |                     |
|-----|-------|---|-----------|-----|-------|----------------|-----|---------|---------------------|
| 2B5 | SAIDI | 5 | MADRD9933 | -   | Cat   | 09/03/22 14:25 | 1   | 276     | Tree                |
| 2B5 | SAIDI | 5 | MADRD9933 | -   | Cat   | 09/03/22 14:25 | 1   | 276     | AMI - No Job/Cause  |
| 2B5 | SAIDI | 5 | MADRD9933 | -   | Cat   | 09/03/22 14:25 | 1   | 276     | Tree                |
| 2B5 | SAIDI | 5 | MADRD9933 | -   | Cat   | 09/03/22 15:25 | 1   | 5,503   | AMI - No Job/Cause  |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 09/06/22 09:49 | 1   | 54      | AMI - No Job/Cause  |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 09/09/22 14:58 | 2   | 33      | Intentional         |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 09/09/22 17:32 | 131 | 9,802   | Public Interference |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 09/09/22 17:33 | 1   | 54      | Other               |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 09/09/22 17:33 | 1   | 54      | Equipment           |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 09/12/22 14:32 | 1   | 25      | AMI - No Job/Cause  |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 09/19/22 05:02 | 105 | 28,786  | Equipment           |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 09/19/22 05:02 | 2   | 1,587   | Equipment           |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 09/19/22 09:46 | 1   | 826     | Other               |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 09/20/22 20:04 | 1   | 1,325   | Unknown             |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 09/20/22 20:39 | 1   | 1,283   | Other               |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 09/20/22 20:39 | 1   | 1,291   | Lightning           |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 09/20/22 20:39 | 1   | 1,283   | Lightning           |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 09/21/22 00:12 | 1   | 145     | AMI - No Job/Cause  |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 09/28/22 14:51 | 1   | 23      | AMI - No Job/Cause  |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 10/05/22 12:09 | 1   | 19      | AMI - No Job/Cause  |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 10/06/22 08:43 | 1   | 232     | AMI - No Job/Cause  |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 10/13/22 18:03 | 1   | 8       | AMI - No Job/Cause  |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 10/20/22 11:33 | 1   | 60      | AMI - No Job/Cause  |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 10/26/22 12:41 | 136 | 11,992  | Equipment           |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 10/29/22 11:05 | 1   | 122     | Equipment           |
| 2B5 | SAIDI | 5 | MADRD9933 | MED | Small | 11/05/22 15:29 | 5   | 1,120   | Wind                |
| 2B5 | SAIDI | 5 | MADRD9933 | MED | Small | 11/05/22 18:59 | 186 | 241,920 | Wind                |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 11/10/22 13:15 | 1   | 208     | AMI - No Job/Cause  |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 11/15/22 11:14 | 1   | 127     | AMI - No Job/Cause  |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 11/27/22 19:45 | 1   | 228     | AMI - No Job/Cause  |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 11/27/22 22:20 | 12  | 892     | AMI - No Job/Cause  |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 11/27/22 22:20 | 12  | 891     | Unknown             |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 12/03/22 08:28 | 1   | 414     | Wind                |
| 2B5 | SAIDI | 5 | MADRD9933 | -   |       | 12/03/22 08:29 | 1   | 414     | AMI - No Job/Cause  |





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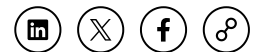
Clean energy journalism for a cooler tomorrow

## Massachusetts kicks off first pilot to shift gas utilities to clean heat

Multiple states see thermal energy networks as a way to clean up gas utilities. Eversource's pilot project will be an important first test of the concept.

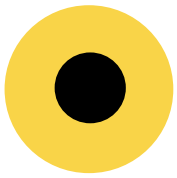


By **Jeff St. John**  
4 June 2024



A drilling crew boring a geothermal well for utility Eversource's thermal energy network pilot project in Framingham, Massachusetts (Eversource)

Gas utilities could be key to the effort to get fossil fuels out of buildings – but only if they stop investing in pipes that deliver fossil gas and instead start building pipes for clean energy.



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pipes that will connect to houses, apartments, commercial buildings, a community college campus, and a fire station. Those pipes will circulate a water-and-glycol solution through 88 boreholes that extend hundreds of feet into the earth, fetching the ambient temperature buried beneath the surface and shuttling it up into buildings.

“The pipe is in the ground, the boreholes have been drilled. We’re ready to turn the pumps on and get going,” said Eric Bosworth, Eversource’s manager of clean technologies.

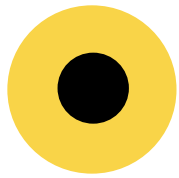
Temperatures remain at about 55 degrees Fahrenheit deep underground, no matter how hot it gets in the summer or how cold it gets in the winter. The liquid flowing into and out of those boreholes, through the pipes, and into the 31 residential and five commercial buildings tied into the Framingham project is therefore cooler in the summer, and hotter in the winter, than the ambient air on the earth’s surface.

That makes it an ideal input for the electric “ground source” heat pumps that Eversource is installing to replace gas furnaces for the approximately 125 customers tied into the new system. Heat pumps are essentially two-way air conditioners that exchange heat and cold from outside to inside buildings, and ground-source heat pumps tend to be much more efficient than “air source” heat pumps that use outside air as a thermal exchange medium.

If scaled up across the country, ground-source heat pumps could dramatically reduce the amount of electricity needed to convert buildings from fossil fuels to electric heating and cooling, according to the U.S. Department of Energy. The problem is that the costs and complexities of drilling boreholes and circulating liquid underground are out of reach for most building owners.

But utilities are in the business of financing large-scale energy projects and paying them off over decades via monthly charges on their customers’ bills. This model should allow utilities to build the infrastructure for ground-source heat pumps at a much lower cost than individual building owners would pay, especially given utility expertise in creating pipeline networks.



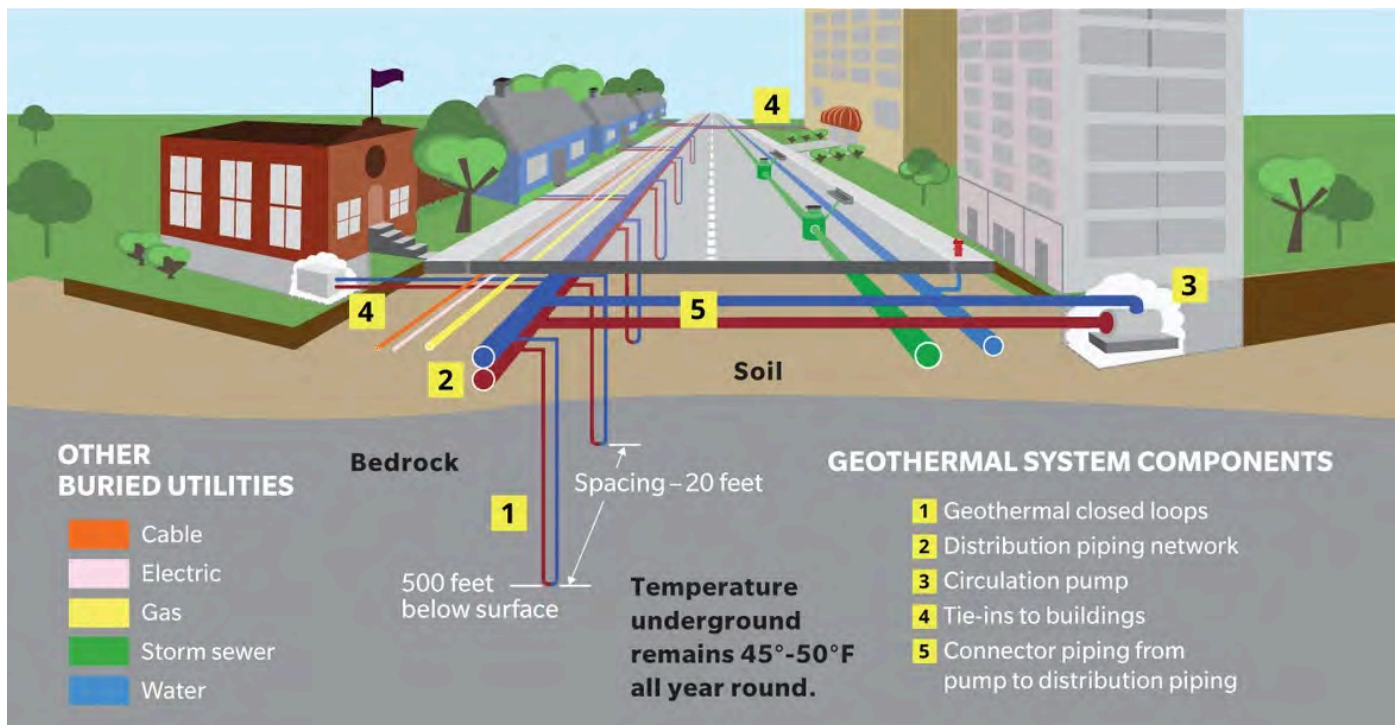


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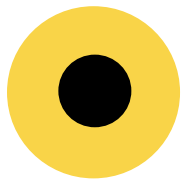
At the same time, Massachusetts gas utilities are facing tens of billions of dollars in costs to maintain aging gas pipelines, all to keep delivering a fossil fuel that's incompatible with the state's climate goals. Advocates of thermal networks say it makes far more sense to channel that money into infrastructure that fits into a carbon-free future – a move that will help the planet and avoid saddling customers with the costs of stranded gas assets.

“We as a utility are well positioned to do this project – the pipes are in the warehouse, the skills are in the workforce,” Bosworth said. “Now we’re really interested in what the economics are” – and how they could allow the utility to scale thermal energy networks beyond a single neighborhood.



A diagram of the system of boreholes and pipes that will share thermal energy among customers equipped with high-efficiency ground-source heat pumps. (Eversource)

## The thermal energy network movement



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broadly is another question, however.

The concept has gained traction in the past few years, with significant pilot projects happening not only in Massachusetts but also in New York state. Legislation allowing thermal networks to move forward has passed or been proposed in Colorado, Maryland, Minnesota, Vermont, and Washington state.

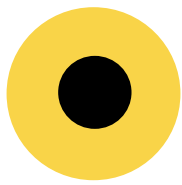
But right now, the effort faces serious regulatory hurdles.

Today's regulatory structures require utilities to supply gas to all customers who want it. And regulators are likely to balk at asking customers to bear the cost of thermal energy networks on top of the cost of keeping gas networks up and running.

"College campuses and other communities can build thermal energy networks – but not gas utilities," Camargo Cortés said.

For that to change, utilities and state regulators have to set up pilot projects like the Framingham thermal energy network loop to vet the engineering and economics, she said. The Building Decarbonization Coalition is one of a number of groups that have been working to create the legal and regulatory structures to make these pilots – and eventually larger-scale change – possible.

Time is of the essence, because the costs of investing in soon-to-be stranded gas pipelines are growing, Camargo Cortés said. In a report released last month, Cambridge, Massachusetts-based nonprofit Home Energy Efficiency Team (HEET), which commissioned the study that inspired the pilot projects in its state, tallied up \$347 billion in U.S. utility investments into gas distribution pipelines that have already been "locked in" – meaning gas utility customers will have to pay them off over the next 50 years. If current plans by gas utilities continue unchecked, another \$698 billion in future capital costs could be piled onto customers, the report found.



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Utilities can't just shut down their gas networks overnight. But neither can they continue with business as usual, investing more and more into a pipeline network that must be used less and less, driving up costs for gas customers. Those customers who can afford to do so will abandon gas for electric heating and appliances to avoid those rising costs, leaving fewer – and poorer – customers to shoulder increasingly high rates just to keep their homes warm.

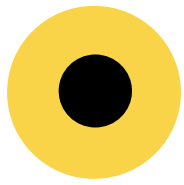


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To interrupt this negative feedback loop, policymakers and regulators must “give the gas companies a way to transition,” Camargo Cortés said. “How do we decommission all this gas pipe in a safe way and in a phased, managed way – one that takes whole neighborhoods at a time, so that it doesn’t become an equity issue?”

## Getting the customers on board

Eversource’s pilot in Framingham is avoiding one big challenge for transitioning gas utilities to thermal energy network utilities: removing fossil gas from the equation. “We’re not touching any of the existing infrastructure,” Bosworth said. Buildings in the pilot are still receiving fossil gas for water heating, cooking, and other uses.

For thermal energy networks to serve the transformational role that groups like HEET and the Building Decarbonization Council envision for them, this problem will need to be confronted. Customers at large will have to agree to ditch fossil gas entirely.

That’s where “removing the ‘obligation to serve’ becomes really important,” Camargo Cortés said, referring to the regulations in every state that require gas utilities to provide gas to any customer in their service territory. “For a gas utility to take one street’s pipes offline requires everyone to agree.”

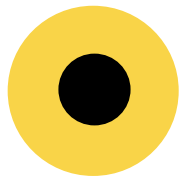
That brings up the issue of how utility customers feel about switching from gas to electric – and what it’s worth to them. On this front, Eversource’s project in Framingham offers a special deal for its participants, one meant to smooth the way to getting enough customers on board to test the broader thermal energy network proposition.



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a low rate that doesn't fully cover the capital and operating costs of the project.

Now that the network is built and ready to operate, the next step is getting all of the customers connected. So far, Eversource has completed or is in the process of extending pipes and installing heat pumps in seven of the 22 residential buildings involved, as well as about a quarter of the 108 apartments of the Framingham Housing Authority complex located along the northwest side of the milelong loop.



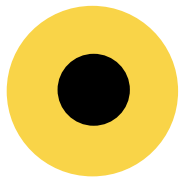
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A map of the neighborhood served by the thermal energy network built by utility Eversource in Framingham, Massachusetts (Eversource)

Eversource expects participating customers to see their monthly energy bills fall by about 20 percent and their carbon emission drop by about 60 percent as they move from gas to ground-source heat pumps. But “that’s a ballpark average,” Bosworth said – the pilot will help to quantify things more accurately.



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us,” he said – a retrofit of their colonial Cape Cod home with a central air system and heating and cooling from a bidirectional ground-source heat pump.

It would be hard for utilities to justify covering all the costs for all the customers involved in thermal energy networks if they’re to scale up beyond pilot projects. But Camargo Cortés highlighted that any costs of making this transition must be compared with the cost of continuing to make investments in a gas pipeline network that must be largely retired, which will also fall on a gas utility’s entire customer base.

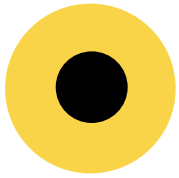
Some customers may be willing to take on the costs of converting their heating systems on their own. Gina Richard, owner of the Corner Cabinet, a kitchen and bath showroom on the northeast corner of the project, said that she’d been looking for options to replace her 20-year-old gas furnace before Eversource approached her about the pilot.

“I think I would have borne some of the cost for the upgrade,” she said. “In our situation, where we had a system approaching end of life in the next five years or so, it was such a win-win for us. If I had been incentivized to join the program for savings and I had to outlay some capital to do the system, I would have done that.”

## The long-term vision

It’s also important to keep an eye on the portion of costs that could fall as these networks are expanded, Bosworth said. For instance, out of the Framingham project’s \$14 million total budget, about \$5.7 million went to building the central pump house and control system that keeps the liquid flowing into and out of the boreholes and throughout the pipe network, he said – assets that could support the network’s expansion to adjacent neighborhoods.

Last year, Eversource and HEET won a \$715,000 grant from the U.S. Department of Energy to study the feasibility of doing just that kind of expansion, Camargo Cortés said. While that study is still underway, “they’re seeing a lot of cost savings from this second loop compared to this first loop,” she said.



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“If you run the numbers with air-source heat pumps, there’s a lot more electric grid buildout that needs to take place, compared to ground-source heat pumps,” he said.

As for customers who refuse to take the thermal energy and electric route, there are options available, Camargo Cortés said. People who want to keep cooking with fossil gas could be offered propane tanks for their stoves, for example.

“I think the biggest thing is how do we create the possibility for whole-system scale transition, where we can really map out transitioning entire communities off gas and into comfortable, affordable, equitable heating for everybody,” Camargo Cortés said. “As long as this is done equitably and everyone is allowed to participate, it can be done fairly. Where it becomes a problem is when some people are excluded.”

Geothermal

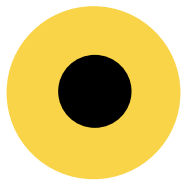
Utilities

Jeff St. John is director of news and special projects at Canary Media. He covers innovative grid technologies, rooftop solar and batteries, clean hydrogen, EV charging and more.

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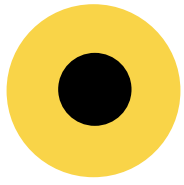
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## Redwood Coast Airport Renewable Energy Microgrid



### The Challenge

As load serving entities, Community Choice Aggregators (CCAs) need to procure utility scale renewable generation and energy storage to serve their customer base. Investor Owned Utilities (IOUs) are working to transition to the sustainable grid of the future by updating interconnection processes, developing new tariff structures, and grappling with the effects of more intermittent renewable energy on the grid. Meanwhile, climate change has increased the frequency and severity of natural disasters, highlighting the importance of keeping critical facilities operating to provide emergency services in times of dire need.

The Redwood Coast Airport Renewable Energy Microgrid Project will demonstrate a replicable business case for deploying microgrids in California that address the needs of these emerging trends.

### Project Innovation + Advantages

This project will demonstrate the first multi-customer, front-of-the-meter microgrid with generation owned by a local CCA (Redwood Coast Energy Authority) and the microgrid circuit owned by an IOU (Pacific Gas & Electric). It will provide low carbon resiliency to a commercial airport and U.S. Coast Guard Air Station, which are among the most critical facilities in the host community. The microgrid will include a megawatt scale PV array directly DC-coupled to a lithium-ion battery system. This will allow the CCA to participate in the CAISO wholesale electricity market. During "blue sky" conditions, the CCA-owned generation system will store solar energy during the day and discharge it during the evening peak when power is needed and wholesale prices are high. When islanded, the

generation system will energize the microgrid, enabling extended operation on 100% renewable energy. The IOU will own, operate, and maintain the microgrid circuit, including protection and control devices, as well as control the microgrid during islanded operation.



Coast Guard Air Station Humboldt Bay

### Anticipated Benefits for California

#### *Demonstrating a replicable business case*

The focus of this project is to deploy standardized, commercially available microgrid technology in an innovative configuration that offers measurable benefits to stakeholders, can be easily replicated, and can be economically viable. CCAs have the ability to finance renewable energy generation and it is typically part of their mission to do so. CCAs also have reason to provide energy storage. The microgrid will provide important resiliency benefits and the incremental cost of siting these generation/storage systems near critical facilities and upgrading the distribution system for microgrid readiness can be small. The Airport Microgrid project will demonstrate the economic viability of this business case, showing how barriers to widespread deployment of multi-customer microgrids can be eliminated.



### Standards, tariffs & agreements that facilitate replication

Pacific Gas & Electric (PG&E) will develop engineering standards, testing protocols, and equipment specifications for multi-customer, front-of-the-meter microgrids within their distribution system. As the CCA administrator, the Redwood Coast Energy Authority (RCEA) will collaborate with PG&E to create experimental tariffs and agreements that allow for the creation and operation of this innovative microgrid project. These tariffs and agreements will become important examples to other IOUs and CCAs, and help to facilitate replication of this business model.

### Increased reliability and resilience

In the event of a prolonged emergency, the large PV array and storage battery will be able to supply nearly continuous power to the airport and the adjoining U.S. Coast Guard station. Due to Humboldt County's remote, isolated location these critical facilities will provide the means to transport critical supplies into and around the region in a large-scale emergency.

### Environmental and economic benefits

Over 3100 MWh/yr of renewable electricity will be generated. This will result in CO<sub>2</sub> emission reductions of over 880 MT/yr. Coupled with energy storage, this system will generate an annual economic benefit of approximately \$356,000. During the construction phase an estimated 37 full time jobs will be created, with \$1.5M in earnings and \$3.4M in economic output. (Note: these values are based on preliminary project estimates.)

### Community choice

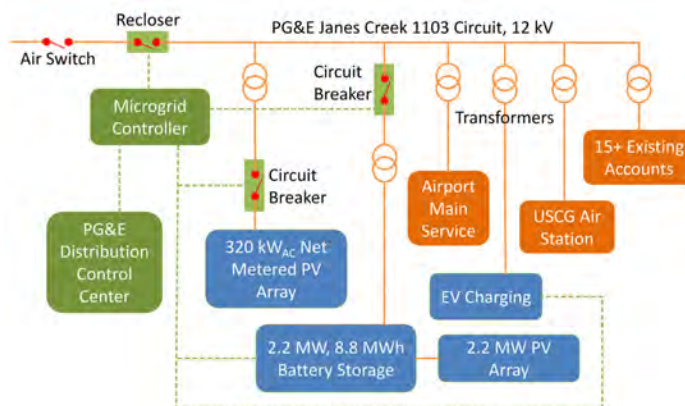
RCEA's CCA program will make significant progress in its mandate to deliver locally produced renewable electricity to its ratepayers while also meeting its energy storage mandate.

### Technological advancements

Innovative direct DC-coupling of the PV and battery systems will result in a more efficient system and will lower project costs by reducing the number of inverters and reducing telemetry requirements for interconnection.

## Major Project Elements

- 2.2 MW<sub>DC</sub> solar photovoltaic array, DC-coupled to energy storage
- 2.2 MW<sub>AC</sub>, 8.8 MWh battery energy storage
- 320 kW<sub>AC</sub> PV system that will offset airport electricity consumption through net metering
- Microgrid control system with distribution control center interface
- Two reclosers with advanced controllers
- Demand response capable electric vehicle charging



## Contacts

**Grant Recipient:** Schatz Energy Research Center, Humboldt State University / (707) 826-4345  
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**Commission Agreement Manager:** Hatice Gecol, Ph.D.  
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Total Project Cost: \$11,323,000  
CEC EPIC Funding: \$5,000,000  
Project Location: California Redwood Coast – Humboldt County Airport, McKinleyville, CA  
Contract Term: August 2018 to March 2023

## Key Partners

California Energy Commission; Schatz Energy Research Center at Humboldt State University; Redwood Coast Energy Authority; Pacific Gas & Electric Company; County of Humboldt; Tesla, Inc.; Schweitzer Engineering Laboratories, Inc.; TRC Companies, Inc.; The Energy Authority, Inc.



Cautio: Photovoltaic system performance predictions calculated by PVWatts® include many inherent assumptions and uncertainties and do not reflect variations between PV technologies nor site-specific characteristics except as represented by PVWatts® inputs. For example, PV modules with better performance are not differentiated within PVWatts® from lesser performing modules. Both NREL and private companies provide more sophisticated PV modeling tools (such as the System Advisor Model at [/sam.nrel.gov](https://sam.nrel.gov)) that allow for more precise and complex modeling of PV systems.

The expected range is based on 30 years of actual weather data at the given location and is intended to provide an indication of the variation you might see. For more information, please refer to this NREL report: The Error Report.

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The energy output range is based on analysis of 30 years of historical weather data, and is intended to provide an indication of the possible interannual variability in generation for a Fixed (open rack) PV system at this location.

RESULTS

78,237 kWh/Year\*

System output may range from 75,444 to 80,443 kWh per year near this location.

| Month     | Solar Radiation<br>( kWh / m <sup>2</sup> / day ) | AC Energy<br>( kWh ) |
|-----------|---------------------------------------------------|----------------------|
| January   | 2.49                                              | 4,043                |
| February  | 3.54                                              | 5,169                |
| March     | 4.21                                              | 6,550                |
| April     | 5.28                                              | 7,692                |
| May       | 5.77                                              | 8,405                |
| June      | 6.24                                              | 8,584                |
| July      | 6.48                                              | 9,105                |
| August    | 5.89                                              | 8,398                |
| September | 5.18                                              | 7,308                |
| October   | 3.75                                              | 5,681                |
| November  | 2.70                                              | 4,128                |
| December  | 2.01                                              | 3,174                |
| Annual    | 4.46                                              | 78,237               |

Location and Station Identification

|                     |                         |        |  |
|---------------------|-------------------------|--------|--|
| Requested Location  | detroit, mi             |        |  |
| Weather Data Source | Lat, Lng: 42.33, -83.06 | 0.6 mi |  |
| Latitude            | 42.33° N                |        |  |
| Longitude           | 83.06° W                |        |  |

PV System Specifications

|                         |                   |     |      |     |     |      |
|-------------------------|-------------------|-----|------|-----|-----|------|
| DC System Size          | 60.25 kW          |     |      |     |     |      |
| Module Type             | Standard          |     |      |     |     |      |
| Array Type              | Fixed (open rack) |     |      |     |     |      |
| System Losses           | 14.00%            |     |      |     |     |      |
| Array Tilt              | 23°               |     |      |     |     |      |
| Array Azimuth           | 180°              |     |      |     |     |      |
| DC to AC Size Ratio     | 1.2               |     |      |     |     |      |
| Inverter Efficiency     | 96%               |     |      |     |     |      |
| Ground Coverage Ratio   | 0.4               |     |      |     |     |      |
| Albedo                  | From weather file |     |      |     |     |      |
| Bifacial                | No (0)            |     |      |     |     |      |
| Monthly Irradiance Loss | Jan               | Feb | Mar  | Apr | May | June |
|                         | 0%                | 0%  | 0%   | 0%  | 0%  | 0%   |
| Monthly Irradiance Loss | July              | Aug | Sept | Oct | Nov | Dec  |
|                         | 0%                | 0%  | 0%   | 0%  | 0%  | 0%   |

Performance Metrics

|                    |       |
|--------------------|-------|
| DC Capacity Factor | 14.8% |
|--------------------|-------|



Cautio: Photovoltaic system performance predictions calculated by PVWatts® include many inherent assumptions and uncertainties and do not reflect variations between PV technologies nor site-specific characteristics except as represented by PVWatts® inputs. For example, PV modules with better performance are not differentiated within PVWatts® from lesser performing modules. Both NREL and private companies provide more sophisticated PV modeling tools (such as the System Advisor Model at /sam.nrel.gov) that allow for more precise and complex modeling of PV systems.

The expected range is based on 30 years of actual weather data at the given location and is intended to provide an indication of the variation you might see. For more information, please refer to this NREL report: The Error Report.

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The energy output range is based on analysis of 30 years of historical weather data, and is intended to provide an indication of the possible interannual variability in generation for a Fixed (open rack) PV system at this location.

RESULTS

78,514 kWh/Year\*

System output may range from 75,711 to 80,728 kWh per year near this location.

| Month     | Solar Radiation<br>( kWh / m <sup>2</sup> / day ) | AC Energy<br>( kWh ) |
|-----------|---------------------------------------------------|----------------------|
| January   | 2.54                                              | 4,136                |
| February  | 3.60                                              | 5,256                |
| March     | 4.24                                              | 6,592                |
| April     | 5.28                                              | 7,685                |
| May       | 5.73                                              | 8,348                |
| June      | 6.18                                              | 8,503                |
| July      | 6.43                                              | 9,030                |
| August    | 5.88                                              | 8,376                |
| September | 5.21                                              | 7,354                |
| October   | 3.80                                              | 5,759                |
| November  | 2.76                                              | 4,220                |
| December  | 2.06                                              | 3,255                |
| Annual    | 4.48                                              | 78,514               |

Location and Station Identification

|                     |                         |        |
|---------------------|-------------------------|--------|
| Requested Location  | detroit, michigan       |        |
| Weather Data Source | Lat, Lng: 42.33, -83.06 | 0.6 mi |
| Latitude            | 42.33° N                |        |
| Longitude           | 83.06° W                |        |

PV System Specifications

|                         |                   |     |      |     |     |      |
|-------------------------|-------------------|-----|------|-----|-----|------|
| DC System Size          | 60.25 kW          |     |      |     |     |      |
| Module Type             | Standard          |     |      |     |     |      |
| Array Type              | Fixed (open rack) |     |      |     |     |      |
| System Losses           | 14.00%            |     |      |     |     |      |
| Array Tilt              | 25°               |     |      |     |     |      |
| Array Azimuth           | 180°              |     |      |     |     |      |
| DC to AC Size Ratio     | 1.2               |     |      |     |     |      |
| Inverter Efficiency     | 96%               |     |      |     |     |      |
| Ground Coverage Ratio   | 0.4               |     |      |     |     |      |
| Albedo                  | From weather file |     |      |     |     |      |
| Bifacial                | No (0)            |     |      |     |     |      |
| Monthly Irradiance Loss | Jan               | Feb | Mar  | Apr | May | June |
|                         | 0%                | 0%  | 0%   | 0%  | 0%  | 0%   |
|                         | July              | Aug | Sept | Oct | Nov | Dec  |
|                         | 0%                | 0%  | 0%   | 0%  | 0%  | 0%   |

| Performance Metrics |       |
|---------------------|-------|
| DC Capacity Factor  | 14.9% |

STATE OF MICHIGAN

BEFORE THE MICHIGAN PUBLIC SERVICE COMMISSION

In the matter of the application of **DTE  
ELECTRIC COMPANY** for authority to  
increase its rates, amend its rate schedules  
and rules governing the distribution and  
supply of electric energy, and for  
miscellaneous accounting authority

Case No. U-21534

ALJ Sally Wallace

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**PROOF OF SERVICE**

I, Mark N. Templeton, certify that an electronic copy of the Accompanying Exhibits DAO-279 to DAO-291 (Part 4 of 4) for the Direct Testimony of Arjun Makhijani on Behalf of Soulardarity and We Want Green, Too was served on the following on July 26, 2024.

| Name/Party                                                                                                                                       | E-mail Address                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|--------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Administrative Law Judge</b><br>Hon. Sally Wallace                                                                                            | <a href="mailto:wallaces2@michigan.gov">wallaces2@michigan.gov</a>                                                                                                                                                                                                                                                                                                                                                                                                                                   |
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|                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                      |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
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|                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
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The statements above are true to the best of my knowledge, information, and belief.

UNIVERSITY OF CHICAGO LAW SCHOOL  
ABRAMS ENVIRONMENTAL LAW CLINIC  
Counsel for Soulardarity and  
We Want Green, Too

Date: July 26, 2024

Sincerely,



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