Twin Cities MSA Greenhouse Gas Inventory

Climate Pollution Reduction Grant Documentation

Metropolitan Council

2025-07-31

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# Executive summary

*This project has been funded wholly or in part by the United States Environmental Protection Agency (EPA) under assistance agreement 00E03476 to the Metropolitan Council. The contents of this document do not necessarily reflect the views and policies of the EPA, nor does the EPA endorse trade names or recommend the use of commercial products mentioned in this document.*

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| Note |
| This document will be updated continuously in preparation of the Metropolitan Council Comprehensive Climate Action Plan (CCAP). Please check back occasionally as we update modify and add new content. You can find a summary of changes in the [Appendix G](#sec-changelog). |

In 2021, the Twin-Cities MSA generated 54.03 million metric tons CO2 equivalent (MMtCO2e) emissions from the energy, transportation, industrial, waste, and agricultural sectors. Transportation was the largest contributor to GHG emissions (33.4%), followed by Industrial (22.9%), and Commercial (21.6%). Carbon sequestration from natural systems offset 4.7% of total emissions. In the methodology sector breakdown, we explain how electricity and natural gas emissions are calculated and apportioned to the residential, commercial, and industrial sectors.

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| Figure 1: Regional emissions by sector and category |

## Emissions through time

Emissions in the region fell by 18.0% from 2005 to 2021. This is principally attributed to decarbonization of the electric grid, which fell 46.9% from 2005 to 2021. Other sectors showed small increases or decreases.

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| Figure 2: Regional emissions by sector through time |

## County Emissions

Different counties have different emission profiles depending on land-use and community characteristics.

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| Figure 3: County emissions by sector in 2021 |

However, most emissions are closely tied to population and a per capita emissions profile shows a more even distribution.

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| Figure 4: County emissions per capita by sector in 2021 |

## Acknowledgements

This document is the result of tremendous work across the Metropolitan Council. Individuals are noted by their name, title, contribution, and division.

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# 1. Mobile combustion

## 1.1 Introduction

Transportation emissions, when grouped together, are one of the largest sources of greenhouse gas emissions nationally, statewide, and locally.

This is the transportation section for estimating on-road emissions. Modes included are motorcycles, passenger cars, intercity buses, light commercial trucks, single unit long-haul trucks, refuse trucks and transit buses. Aviation data provided are considered preliminary at this time.

Note that this does not include freight rail, light rail, and other transportation emissions.

## 1.2 2021 emissions

Transportation emissions totaled 15.59 MMtCO2e, accounting for 33% of regional emissions in 2021.

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| Figure 1.1: 2021 transportation emissions by county |

We can also view this data broken out by fuel type.

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| Figure 1.2: 2021 annual emissions transportation by fuel type |

## 1.3 Historical emissions

Despite a 10.3% reduction in the transportation sector due to the Covid pandemic, emissions in this sector rebounded to in 2021.

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| Figure 1.3: Transportation emissions, 2002-2021 |

# 2. Methods and data sources

## 2.1 Methodological framework

Transportation emissions are available for motorcycles, passenger cars, intercity buses, light commercial trucks, single unit long-haul trucks, refuse trucks and transit buses using EPA data sources. We use a geographic, or territorial accounting method, aligning with Scope 1 in the Greenhouse Gas Protocol. Geographic methods account for any transportation emissions taking place within a geographic boundary, regardless of origin or destination (Fong et al. 2021).

Geographic emissions are essential for quantifying air pollution experienced by people living in the area, but they do not give information on the logistic decisions of individuals.

## 2.2 Data sources

### 2.2.1 EPA emissions data

The EPA releases various emissions estimates as part of several programs and initiatives.

All datasets are compiled from Sparse Matrix Operator Kernel Emissions (SMOKE) Flat File 10 (FF10) formatted data downloaded from the EPA website. SMOKE FF10 is a standardized format regularly released by the EPA for NEI, EQUATES, and Air Emissions Modeling platforms (CMAS 2024, sec. 2.2.3).

SMOKE FF10 files were processed using [read\_smoke\_ff10()](file:///Users/rotenle/Downloads/data-raw/_read_smoke_ff10.R), which reads in the raw data, records relevant metadata, filters to only include relevant counties and pollutants, and saves an intermediary dataset. These intermediary datasets are read back in, combined, and saved.

SMOKE FF10 data were aggregated to include all MOVES processes for on- and off-network vehicle operation, including running, starting, and idling exhaust, tire and brake wear, evaporative permeation, fuel leaks, and fuel vapor venting, and crankcase exhaust (CMAS 2024, sec. 2.7.4.9). [[1]](#footnote-1)

Direct URLs and download information are available in the [EPA downloads guide](file:///Users/rotenle/Downloads/data-raw/epa/README_epa_downloads.html).

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| Table 2.1: Intermediary datasets and processing scripts   | Data source | Dataset | Processing script | | --- | --- | --- | | National Emissions Inventory | epa\_nei\_smoke\_ff.RDS | <a href="data-raw/epa\_nei\_smoke\_ff.R">data-raw/epa\_nei\_smoke\_ff.R</a> | | EQUATES | equates\_cmas\_mn\_wi.RDS | <a href="data-raw/epa\_equates\_read.R">data-raw/epa\_equates\_read.R</a> | | Air Emissions Modeling | onroad\_mn\_wi.RDS | <a href="data-raw/epa\_air\_emissions\_modeling\_onroad.R">data-raw/epa\_air\_emissions\_modeling\_onroad.R</a> | |

Each data source and year uses a different MOVES edition. These are listed in [Table 2.2](#tbl-epa-source-moves-edition-year).

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| Table 2.2: On-road pollutants available by year and EPA data source   | Data source | MOVES edition | Years | | --- | --- | --- | | Air Emissions Modeling | MOVES4 | 2021, 2022 | | National Emissions Inventory | MOVES3 | 2020 | | EQUATES | MOVES3 | 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019 | |

Various pollutants are available.

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| Table 2.3: On-road pollutants available by year and EPA data source   | Data source | Years | Pollutants | | --- | --- | --- | | Air Emissions Modeling | 2021, 2022 | CO2, CH4, N2O, CO, NO, NOx, SO2, PM2.5, PM10, NH3 | | National Emissions Inventory | 2020 | CO2, CH4, N2O, CO, NOx, SO2, NH3, PM2.5, PM10 | | EQUATES | 2018, 2019 | CO2, CH4, N2O, CO, NO, NOx, SO2, PM2.5, PM10, NH3 | | EQUATES | 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017 | CO2, CH4, CO, NO, NOx, SO2, PM2.5, PM10, NH3 | |

Pollutant descriptions

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| Table 2.4: Pollutants provided by EPA datasets   | Pollutant | Pollutant code | Description | | --- | --- | --- | | CH4 | CH4 | Methane | | CO | CO | Carbon Monoxide | | CO2 | CO2 | Carbon Dioxide | | N2O | N2O | Nitrous Oxide | | NH3 | NH3 | Ammonia | | NO | NO | Nitric Oxide | | NOx | NOX | Nitrogen Oxides | | PM2.5 | PM10-PRI | PM10 Primary (Filt + Cond) | | PM10 | PM25-PRI | PM2.5 Primary (Filt + Cond) | | SO2 | SO2 | Sulfur Dioxide | | VOC | VOC | Volatile Organic Compounds | |

Vehicle and fuel types

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| Table 2.5: Vehicle and fuel types provided by EPA datasets   | Vehicle weight label | Fuel types | Vehicle types | | --- | --- | --- | | Passenger | Gasoline | Motorcycles, Passenger cars, Passenger trucks | | Passenger | Diesel | Passenger cars, Passenger trucks | | Passenger | Electric | Passenger cars | | Passenger | Ethanol (E-85), Electric | Passenger cars, Passenger trucks | | Passenger | Ethanol (E-85) | Passenger cars, Passenger trucks | | Buses | Gasoline | Intercity buses, Transit buses, School buses | | Buses | Diesel | Intercity buses, Transit buses, School buses | | Buses | Compressed natural gas (CNG) | Intercity buses, Transit buses | | Buses | Gasoline | Transit buses, School buses | | Buses | Diesel | Transit buses, School buses | | Trucks | Gasoline | Light commercial trucks, Refuse trucks, Single unit short-haul trucks, Single unit long-haul trucks, Motor homes, Combination short-haul trucks | | Trucks | Diesel | Light commercial trucks, Refuse trucks, Single unit short-haul trucks, Single unit long-haul trucks, Motor homes, Combination short-haul trucks, Combination long-haul trucks | | Trucks | Compressed natural gas (CNG) | Single unit long-haul trucks | | Trucks | Compressed natural gas (CNG) | Refuse trucks, Single unit long-haul trucks | | Trucks | Compressed natural gas (CNG), Ethanol (E-85), Electric | Refuse trucks, Single unit long-haul trucks, Light commercial trucks | | Trucks | Compressed natural gas (CNG), Ethanol (E-85) | Refuse trucks, Single unit long-haul trucks, Light commercial trucks | | Trucks | Gasoline | Light commercial trucks, Refuse trucks, Single unit short-haul trucks, Single unit long-haul trucks, Motor homes | | Trucks | Compressed natural gas (CNG), Ethanol (E-85), Electric | Single unit long-haul trucks, Light commercial trucks | | Trucks | Gasoline | Light commercial trucks, Single unit short-haul trucks, Single unit long-haul trucks, Motor homes, Combination short-haul trucks | |

#### 2.2.1.1 National Emissions Inventory

The [National Emissions Inventory](https://www.epa.gov/air-emissions-inventories/national-emissions-inventory-nei) (NEI) is a comprehensive and detailed estimate of air emissions of criteria pollutants, criteria precursors, and hazardous air pollutants from air emissions sources. The county-level GHG emissions included in the NEI for this category are calculated by running the MOVES model with State-, Local-, and Tribal-submitted activity data and EPA-developed activity inputs based on data from FHWA and other sources (USEPA 2023c).

NEI data were pulled using the [EnviroFacts](https://enviro.epa.gov/) API and processed in R scripts: [epa\_nei.R](file:///Users/rotenle/_meta/data-raw/epa_nei.R) and [epa\_nei\_envirofacts.R](file:///Users/rotenle/Downloads/data-raw/epa_nei_envirofacts.R).

NEI SMOKE FF10 data are processed in [epa\_nei\_smoke\_ff.R](file:///Users/rotenle/Downloads/data-raw/epa_nei_smoke_ff.R).

NEI on-road regional summaries are processed in [epa\_nei\_onroad\_emissions.R](file:///Users/rotenle/Downloads/data-raw/epa_nei_onroad_emissions.R).

Ultimately, NEI data used in the Metropolitan Council inventory were compiled from SMOKE FF10 for year 2020.

##### 2.2.1.1.1 Verification and validation

NEI data were cross-verified by comparing county level emissions totals compiled from NEI EnviroFacts, NEI data summaries by region, and compiled SMOKE FF10.

[epa\_verify\_nei\_envirofacts\_smoke.R](file:///Users/rotenle/Downloads/data-raw/epa_verify_nei_envirofacts_smoke.R) found that data compiled from SMOKE FF10 and regional summaries aligned exactly for year 2020 and closely for other years. Similarly, data compiled from EnviroFacts also aligned closely with SMOKE FF10 and regional summaries.

Data published on the EPA website are subject to change at any time. Every effort was taken to align versions, model runs, and other opportunities for differentiation.

#### 2.2.1.2 EQUATES

EQUATES (EPA’s Air QUAlity TimE Series) is a set of modeled emissions and supporting data developed by EPA scientists spanning years 2002 to 2019. EQUATES is particularly useful in that it uses modern source classification codes (SCCs) to provide a continuous time series (K. M. Foley et al. 2023).

Between the 2008 and 2011 NEI releases, the EPA completed major changes to their source classification codes (SCCs), which rendered direct comparison between 2008 and prior years with 2011 and later years impossible.

EQUATES is based on the 2017 NEI and uses MOVES3 (K. M. Foley et al. 2023).

EQUATES data are available for years 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018 and 2019.

EQUATES SMOKE FF10 data are processed in [epa\_equates\_read.R](file:///Users/rotenle/Downloads/data-raw/epa_equates_read.R).

##### 2.2.1.2.1 Verification and validation

Though EQUATES datasets are available on the EPA file transfer site and the CMAS Data Warehouse Google Drive, individual file names and file contents were identical.

##### 2.2.1.2.2 Limitations

In addition to limitations described in [Section 2.2.1.4](#sec-epa-emissions-limitations), EQUATES has its own set of limitations.

* EQUATES does not contain emissions estimates for N2O (nitrous oxide) for years 2002-2017. N2O was added to the EPA Emissions Modeling Framework (EMF) after EQUATES was compiled. N2O does not affect air quality monitoring and so was not included in older emissions work (K. Foley, Eyth, and Allen 2024). When compared with the NEI and Air Emissions Modeling, including N2O in total CO2e resulted in a maximum difference of around 3% for some counties and years. See [epa\_verify\_n2o\_differences.R](file:///Users/rotenle/Downloads/data-raw/epa_verify_n2o_differences.R) for more detail.
* EQUATES includes only on-road emission sources.

#### 2.2.1.3 Air Emissions Modeling Platforms

The EPA continually works on emissions inventories for various projects.

Air Emissions Modeling data are available for several years, but years 2021 and 2022 are used in the final inventory.

Both the 2021 and 2022 estimates are based on the 2020 NEI USEPA (2024b).

Air Emissions Modeling SMOKE FF10 data are processed in [epa\_air\_emissions\_modeling\_onroad.R](file:///Users/rotenle/Downloads/data-raw/epa_air_emissions_modeling_onroad.R).

##### 2.2.1.3.1 Verification and validation

Air Emissions Modeling data are only available from a single consistent website, and so verification across locations was not necessary.

##### 2.2.1.3.2 Limitations

In addition to limitations described in [Section 2.2.1.4](#sec-epa-emissions-limitations), Air Emissions Modeling has its own set of limitations.

* Air Emissions Modeling datasets are in active development and subject to change.

#### 2.2.1.4 Consistent limitations

* The NEI, EQUATES, and Air Emissions Modeling platforms are based on MOVES, which does not account for activity on local roads.
* NEI, EQUATES, and Air Emissions modeling use different MOVES editions (see [Table 2.3](#tbl-epa-source-pollutant-year)), which may result in discrepancies between years.
* To reduce run times, the EPA uses fuel months to represent summer and winter fuels. The month of January represents October through April (winter), while July represents May through September (summer) (USEPA 2023a, sec. 5.6.6.2). Variation within the summer and winter months is not accounted for using this method.
* The 2020 NEI had particular challenges due to the COVID-19 pandemic
* Minnesota did not submit custom data inputs for the 2020 NEI, meaning that inputs to MOVES were based on national default values. Wisconsin submitted custom data for VMT, vehicle population, and road type distribution. Both Minnesota and Wisconsin submitted data for 2017, 2014, and 2011 USEPA (2015).
* The NEI augmented vehicle miles traveled (VMT) data for Minnesota and Wisconsin in 2020 using federal and state-level datasets due to data availability issues (USEPA, Godfrey, and Eyth 2022).
* To reduce model run-time, the EPA groups counties together and only runs MOVES on a single representative county. The resulting MOVES emissions factors are multiplied by county-specific activity data (including VMT, vehicle population, hourly speed distribution, among others) to get county-specific emissions (USEPA 2023a, sec. 5.6.2.1). Effectively, emissions factors are generated on a single representative county, and are then applied to similar counties.

##### 2.2.1.4.1 Nitrous oxide (N2O) availability

Though nitrous oxide N2O has a high global warming potential ([Section A.2](#sec-gwp)), the amount of N2O released is relatively small when compared to other sectors.

N2O is unavailable in EQUATES, except years 2018 and 2019.

### 2.2.2 State DOT data

As required by federal law, Minnesota and Wisconsin state departments of transportation (MnDOT and WisDOT) report various traffic measures for planning, forecasting, and various analysis endeavors.

#### 2.2.2.1 Vehicle miles traveled

Vehicle miles traveled (VMT) is a standardized measure created by multiplying average annual daily traffic (AADT) by centerline miles. AADT is an estimate of the total vehicles on a road segment on any given day of the year in all directions of travel. VMT and AADT are common traffic measures and standardized across the United States.

MnDOT and WisDOT derive VMT using traffic counts from continuous and short term traffic monitoring sites. These raw counts are adjusted by multiplying seasonal, day-of-week, and axle adjustment factors WisDOT (2023). Data is not collected for every site every year, but the data are sufficient for year-over-year comparisons.

##### 2.2.2.1.1 County vehicle miles traveled

We consider county-level data to be of the highest quality and most reliable measure of VMT.

These data were compiled from MnDOT and WisDOT county level reports. MnDOT provides Excel workbooks with VMT by county and route system on their [website](https://www.dot.state.mn.us/roadway/data/data-products.html). These were downloaded, filtered to include the relevant counties, and aggregated to the county level by summing VMT by county/route system. Processing code can be found in [mndot\_vmt\_county.R](file:///Users/rotenle/Downloads/data-raw/mndot_vmt_county.R).

VMT data for 2015 were interpolated at the county and year level using the midpoint method.[^ MnDOT VMT for year 2015 is unavailable due to significant and fundamental changes in underlying data structure that make directly comparing data prior- and post-2015 inappropriate. However, our interpolation here is based on the county level summary of all VMT and use for comparison purposes only. We used the midpoint method, which is the average of the observation directly before and directly after the missing data point.]

WisDOT publishes PDF tables with county-level VMT. These were downloaded and data was extracted using [{tabulapdf}](https://docs.ropensci.org/tabulapdf/), an R package interfacing with the Tabula PDF extractor library. Processing code can be found in [wisdot\_vmt\_county.R](file:///Users/rotenle/Downloads/data-raw/wisdot_vmt_county.R).

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| Figure 2.1: County annual vehicle miles traveled |

##### 2.2.2.1.2 City vehicle miles traveled

City VMT is available only for a select number of cities, townships, unorganized areas (CTUs).

These data were compiled from MnDOT city and route system reports available on their [website](https://www.dot.state.mn.us/roadway/data/data-products.html). Reports were downloaded and aggregated at the CTU level by summing VMT up for all route systems. Processing code can be found in [mndot\_vmt\_ctu.R](file:///Users/rotenle/Downloads/data-raw/mndot_vmt_ctu.R).

Due to limitations in data availability and consistency, not all CTUs in the 7-county metro region are included.

* CTUs without reported data prior to 2014 are excluded.
* CTUs without sampled data on local route systems (including Municipal State Aid Streets) during any year from 2017-2023 are excluded. See more about route system designations in [mndot\_route\_system.R](file:///Users/rotenle/Downloads/data-raw/mndot_route_system.R).
* 2015 data were interpolated in the same manner as the county VMT data.
* Shoreview, Blaine, and West Saint Paul are split among more than one county. For some CTU/county/year combinations, only data from 2016 onward were available. For consistency in the time series, we assigned 2016 VMT data to year 2015 for these CTU/county combinations.
* Due to geographic data source differences, MnDOT reports a small amount of VMT invalid CTU/county combinations (i.e., Minneapolis, a Hennepin County CTU, centerline miles and VMT reported in Anoka County). We discussed these anomalies with MnDOT staff and determined this to be a non-issue. The county designations for each CTU were corrected such that summing to the CTU by the CTU name determines the total VMT for each CTU No changes to county designation were made to CTUs known to be split across multiple counties (Chanhassen, Saint Anthony and Spring Lake Park).

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| Figure 2.2: City annual vehicle miles traveled |

#### 2.2.2.2 Limitations

* AADT/VMT data rely on modeling, and not every site will have new observed data every year.
* AADT/VMT are generally estimated for high-use arterial roads and highways, leaving most local roads out.
* We may want to consider using non-permanent counters and/or counters from just outside the study region to increase the total number of calibration roads.

## 2.3 Limitations

* Geographic accounting methods
  + Geographic accounting methods do not account for the decisions or travel behavior of individuals within the geographic boundaries.
  + Within the Twin Cities region, this method will show high emissions per capita in low population areas with significant vehicle traffic, such as a small town with a major freeway. The residents of the small town are not responsible for the emissions of vehicles passing through their town without stopping, but they are subject to the air pollution associated with those trips. Additionally, the city governing body cannot expect to reduce emissions from freeway traffic, as the road is out of their jurisdiction.
  + We will take these limitations into account and plan to mitigate wherever possible for CTU-level inventories and forecasts.

## 2.4 Validation

### 2.4.1 Correlation with related data

We would expect counties with higher population to have higher emissions and VMT.

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| Figure 2.3: County population and transportation emissions |

# 3. Aviation Data

Aviation emissions are derived from three data sources: Metropolitan Airport Commission (MAC) fuel distribution (2005, 2021), MAC Aircraft emission estimates (2016-2020), and MPCA state GHG inventories. Fuel distribution at the airport is the most straight-forward approach, as it involves applying a direct emission factor for jet fuel to the total amount of fuel distributed. As aircraft are generally only fueled for one flight at a time, we are effectively capturing emissions for aircraft flights departing MSP. The assumption is that any given airport (MSP in this case), should be responsible for half of emissions for each arrival and departure, with the complementary departure/recipient airport being responsible for the other half.

The second data source, MAC provided emissions are also a highly useful source, with the one overlapping year (2021) resulting in an almost identical emission estimate. However, because it lacks the explicit activity data, we prefer using the fuel distribution.

The final data source, which we used to in-fill interstitial years, 2006-2015, relies on MPCA statewide aviation emission estimates. Here, we calculated the proportion of MSP aviation emissions relative to statewide emissions, and used a time-series imputation method to fill in the interstitial years’ proportions. Then, we recalculated MSP emissions by multiplying the interpolated proportion by the statewide emission estimate. This method proved superior to directly imputing the MSP emissions between 2005 and 2016-2021 (i.e. not using the state data in any form), as those interpolations resulted in three years with MSP emission estimates exceeding the statewide emission estimate.

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| Figure 3.1: Comparison of aviation emission interpolations |

# 4. Electricity

## 4.1 Introduction

Emissions from the electricity generation sector have declined by 46.9% in the region since 2005, largely as a result of transitions in the grid towards energy sources such as wind and solar (MPCA 2023). In 2023, Minnesota Governor Walz signed a bill mandating a statewide carbon-free electricity standard by 2040. The law “establishes a standard for utilities to supply Minnesota customers with electricity generated or procured from carbon-free resources, beginning at an amount equal to 80% of retail sales for public utility customers in Minnesota in 2030 and increasing every 5 years to reach 100% for all electric utilities by 2040. The bill also requires that, by 2035, an amount equal to at least 55% of an electric utility’s total retail electric sales to customers in Minnesota must be generated or procured from eligible energy technologies.” Wisconsin has not adopted a similar carbon-free electricity standard, but a Wisconsin DNR report noted both the economic gains from such to the renewable energy economy in the state, as well as the opportunities for decarbonization (Holt 2019).

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Table 4.1: Grid Mix for MROW subregion of 2021 eGRID   | Energy.Source | Percentage | | --- | --- | | Coal | 39.6% | | Oil | 0.2% | | Gas | 10.6% | | Other Fossil | 0.10% | | Nuclear | 8.6% | | Hydro | 4.4% | | Biomass | 0.8% | | Wind | 34.6% | | Solar | 0.9% | | Geothermal | 0.0% | | Other | 0.2% | | Unknown/Purchased Fuel | N/A | |

### 4.1.1 Results

### 4.1.2 2021 county and subsector breakdown

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| Figure 4.1: 2021 electricity emissions by sector |
| Figure 4.2: Baseline electricity emissions |
| Figure 4.3: 2021 city level electricity emissions |

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# 5. Methods and data sources

## 5.1 Methods

The general workflow for quantifying electricity emissions is to identify all of the electric utilities that operate within our study area, collect any reporting they provide to the states of Minnesota and Wisconsin about the amount of energy delivered to all their customers (with reference to federal reporting sources where state-level reporting gaps exist), and apply EPA-provided emissions factors to the reported activity/energy deliveries to calculate estimated emissions. Methodologies for allocating utility activity reports to counties varies across MN and WI and are further described in the following section. Most inputs we use in the construction of our electricity emissions data set are of the highest quality rank ([Table B.2](#tbl-quality-rank)), as they are either direct government-created data (e.g., emissions factors) or data reported to state/federal authorities (e.g., regulatory filings). However, for two Minnesota electric utilities – Elk River Municipal Utilities (Elk River Municipal Utilities 2022) and New Prague Utilities Commission (New Prague Utilities Commission 2022) – where regulatory filing data could not be sourced to quantify electricity deliveries, we referred to financial reporting documents published by the utilities.

Total regional emissions (Emissionsr) represents the sum of all recorded energy deliveries by utility *i* within county *j*, where *i* refers to each of the electric utilities operating across our region, and *j* refers to the eleven counties included in this inventory. Our regional total therefore represents an aggregation of electricity deliveries for all distinct utility-county records.

Our inventory takes a “demand-side” approach to emissions quantification and seeks to aggregate all reported delivery of energy to ALL customers served by utilities (meaning all customer types, inclusive of residential, commercial, industrial, and government accounts). This means that energy loss and use experienced by utilities in the process of energy generation and transmission, and delivery and resale to utilities operating outside of our study area, are *not* directly reflected in the numbers attributed to counties. The U.S. Energy Information Administration (EIA) estimates that annual electricity transmission and distribution (T&D) losses averaged about 5% of the electricity transmitted and distributed in the United States in 2018 through 2022. (Administration 2023)

While our primary data collection does not include a breakout of electricity deliveries by sector, we do leverage year 2021 NREL SLOPE forecasts of electricity consumption (built from a base year of 2016 observed data) by sector (residential, commercial, industrial) at the county level to calculate modeled proportions of consumption by sector, which we then apply to our aggregate numbers to calculate estimated emissions *by sector* NREL (2017).

### 5.1.1 Identifying utilities in scope

To identify the electric utilities that operate within our 11-county study area, we referred to maps and geospatial datasets capturing utility service areas in Minnesota and Wisconsin. To identify Wisconsin electric utilities, we downloaded the Electric Service Territory map maintained by the Wisconsin Public Service Commission (Wisconsin Public Service Commission and Tomaszewski 2024). To identify Minnesota electric utilities, we downloaded the Electric Service Territory map maintained by the Minnesota Public Utilities Commission and the Minnesota IT Geospatial Information Office(Office 2023).

### 5.1.2 Collecting and aggregating activity data from utilities

#### 5.1.2.1 County-level activity data

After identifying which utilities operate within our study area within each state, we collect reporting submitted by these utilities to the relevant state and federal authorities and use a variety of approaches, depending on data availability, to allocate utility activity/energy deliveries to specific counties. For the state of Minnesota, we collected reports provided by all in-scope utilities for years 2014-2023. For year 2021, additional manual data collection efforts were completed to guarantee a complete data set, since reports for all in-scope utilities were unfortunately not available for all years. As needed, data for other county-years could be finalized in a similar fashion.

##### 5.1.2.1.1 Minnesota

All electric utilities authorized to do business in Minnesota are required to file an annual data report pursuant to MN Rules Chapter 7610. The Minnesota Public Utilities Commission makes these reports searchable through an [eFiling Site](https://www.edockets.state.mn.us/EFiling/edockets/searchDocuments.do?method=eDocketsResult&docketYear=22&docketNumber=19), and downloadable as Excel workbooks (Commerce 2005). For each utility identified in [distinct\_electricity\_util\_type\_MN.RDS](file:///Users/rotenle/Downloads/data/distinct_electricity_util_type_MN.RDS) (a data product of [minnesota\_electricUtilities.R](file:///Users/rotenle/Downloads/data-raw/minnesota_electricUtilities.R), a script that looks for intersections between electric utility service areas and our Minnesota counties), we downloaded the relevant 2021 annual reports from this site (see note about Great River Energy in the previous section for caveats), except for North Branch Municipal Water and Light, which did not submit a 2021 report (we used their 2022 report as a substitution). Elk River Municipal Utilities and New Prague Utilities Commission did not file reports for 2021 or 2022, and so we used financial reports to identify their total electricity delivered; both utilities operated within only one county in our study area, which meant no estimation/allocation was necessary.

We wrote code to extract the county-level data reported in the report section titled “ITS DELIVERIES TO ULTIMATE CONSUMERS BY COUNTY FOR THE LAST CALENDAR YEAR” on the relevant annual data report Excel workbooks compiled into a folder directory, and created a table with three columns: county, utility, and mWh\_delivered (megawatt-hours). By compiling this data for all utilities found to operate within our study area, aggregating all electricity deliveries at the county level becomes possible.

##### 5.1.2.1.2 Wisconsin

All municipal and investor-owned utilities authorized to do business in Wisconsin are required to file an annual report with financial and operational information pursuant to Wis. Stat. § 196.07. The Public Services Commission of Wisconsin makes these reports searchable through an [E-Services Portal](https://apps.psc.wi.gov/ARS/annualReports/default.aspx), and downloadable as either PDFs or Excel workbooks, with options to export only specific portions of the reports as spreadsheets (Public Service Commission of Wisconsin 2022). For each utility identified in [distinct\_electricity\_util\_type\_WI.RDS](file:///Users/rotenle/Downloads/data/distinct_electricity_util_type_WI.RDS) (a data product of [wisconsin\_electricUtilities.R](file:///Users/rotenle/Downloads/_energy/data-raw/wisconsin_electricUtilities.R), a script that looks for intersections between electric utility service areas and our Wisconsin counties), we downloaded the relevant 2021 annual reports from this site.

A similar process was followed for the four Wisconsin cooperative utilities for which we referenced federal regulatory filings data to populate our dataset of electricity deliveries.

Because of the small amount of data, and the different data structures of the reports for municipally-, cooperatively-, and investor-owned utilities in Wisconsin, we hard-coded observed information into data frames rather than extracting data through a web scraper or document analyzer (see [processed\_wi\_electricUtil\_activityData.R](file:///Users/rotenle/Downloads/data-raw/processed_wi_electricUtil_activityData.R)).

#### 5.1.2.2 City-level activity data (seven-county metro in MN only)

No regulatory requirements in Minnesota or Wisconsin directly require utilities make city-level reports on electrical or natural gas usage data activity publicly available in a manner similar MN Rules Chapter 7610’s requirement for public county-level reporting. In alignment with *climate planning statute*, the Met Council is leading an effort to collect this information on behalf of cities and townships in the seven-county region as a constituent part of the greenhouse gas inventories being developed by the Council to support communities in their own local climate planning as required by state statute and Imagine 2050 minimum requirements. This data collection effort entails 1) direct processing of real, city-sector level data provided by utilities in our region, as well as 2) a series of modeling efforts geared towards addressing missingness in our city/township dataset, as well as disaggregation of coarser numbers provided by utilities (e.g., combined data for commercial/industrial sectors) into residential, commercial, and industrial numbers.

##### 5.1.2.2.1 Processing utility-provided data

Xcel, the largest electric utility in our region, publishes Community Energy Reports (Energy, n.d.) that document energy deliveries to specific communities in their service area. We gathered this data for years 2015-2022 and compiled it into the final .RDS file [xcel\_activityData\_NREL\_2015\_2022\_process.RDS](file:///Users/rotenle/Downloads/data/xcel_activityData_NREL_2015_2022_process.RDS).

[minnesota\_xcelCommunityReports\_electricity.R](file:///Users/rotenle/Downloads/_energy/data-raw/minnesota_xcelCommunityReports_electricity.R) includes all data processing steps necessary to process the nearly 1000 files (one for each city-year combination) made available on the Community Energy Reports site. The function get\_files identifies and extracts relevant info (e.g., city name) from all data files, while process\_file reads detailed electricity consumption data from sections titled “Standard Community Report” in each Excel workbook. Key metrics, such as kilowatt-hours delivered (kWh\_delivered) and utility-reported carbon emissions (util\_reported\_co2e), are then transformed into aggregated datasets (Xcel\_activityData\_2015\_2023) at the utility-year-county level.

Ambiguities in sector classifications, particularly the “Business” category, are addressed through proportional disaggregation using NREL-modeled emissions proportions. This process incorporates additional datasets, such as nrel\_slope\_city\_emission\_proportions.RDS, to allocate energy and emissions between commercial and industrial sectors. Geographic integration (i.e., disaggregating CTUs with footprint in multiple counties) is achieved using cprg\_ctu and ctu\_population, enabling population-based allocation of activity/utility-reported emissions to constituent COCTU units.

Final outputs of [minnesota\_xcelCommunityReports\_electricity.R](file:///Users/rotenle/Downloads/_energy/data-raw/minnesota_xcelCommunityReports_electricity.R) include clean, joined datasets (xcel\_activityData\_NREL\_2015\_2022\_process.RDS) and visualizations that compare utility-reported sector proportions to modeled values. *More to say here before modeling missingness section?*

#### 5.1.2.3 Modeling missingness

Content to come

#### 5.1.2.4 Emissions factors

To transform electricity deliveries (recorded in mWh) into emissions in metric tons CO2e, we referenced Emissions & Generation Resource Integrated Database (eGRID) summary data for the MROW subregion (Midwest Reliability Organization - West) (USEPA 2021a).

This dataset provides estimates in lbs/mWh for CO2, CH4, N2O, and CO2e emissions based on MROW’s sub-regional electricity generation grid mix; converting this factor to metric tons per mWh and multiplying the county-level mWh estimates yields an estimate for CO2e. To generate this sub-regional estimate, eGRID first calculates estimated emissions at the plant level, and assigns plants to regions. By using an emissions factor that is localized, our inventory accounts for the specific grid mix in our study area (see the grid mix linked to the eGRID MROW emissions factor used in this inventory below). Per the eGRID technical guide, “the subregions were defined to limit the import and export of electricity in order to establish an aggregated area where the determined emission rates most accurately matched the generation and emissions from the plants within that subregion.”

## 5.2 Utility Activity Data

### 5.2.1 Minnesota

Under Minnesota Administrative Rules Chapter 7610 (Commerce 2005), utilities are required to file an annual data report that supports the identification of “emerging energy trends based on supply and demand, conservation and public health and safety factors, and to determine the level of statewide and service area needs” (Minnesota Department of Commerce 2022). This includes a report of county-level energy deliveries (reported in megawatt-hours, commonly written as mWh). Because the information is structured in this manner, electricity emissions at the county-level can be estimated as a direct function of energy deliveries to counties reported by utilities.

One utility operating within our study area, Great River Energy (GRE), is a non-profit wholesale electric power cooperative which provides wholesale power and delivery services to 28 Minnesota-based electric cooperatives, which collectively own GRE and provide retail electric service. They are the primary supplier of energy (>99%) to the cooperative utilities operating in our study area. Though most electricity suppliers having relationships with Minnesota electric utilities do not file these annual data reports, GRE does, given their unique hybrid wholesale/transmission structure and cooperative ownership model. As a result, while we keep only GRE’s reporting in our data collection for county-level electricity deliveries, we exclude reporting from these subsidiary retail electric cooperatives, in order to avoid double counting electric deliveries. We use GRE’s reported deliveries to our 9 Minnesota study area counties as a full substitution for the deliveries of these utilities, which may represent a marginal undercount given that marginal-to-negligible amounts of energy delivered by these retail cooperatives came from other other sources, per their annual reports.

### 5.2.2 Wisconsin

Under Wis. Stat. § 196.07, investor- and municipally-owned electric utilities operating within the state of Wisconsin must submit annual reports to the State which include an array of information related to utility finance and operations, including key figures leveraged in our data collection, such as total energy deliveries made (in units of *kWh*) and total number of customer accounts within each county (Wisconsin State Legislature 2024).

Of the seven in-scope electric utilities, only three (the investor- and municipally-owned utilities) were required to make these reports to the State in 2021 (four of the in-scope electric utilities are cooperative utilities); state data was leveraged in this case. For the four utilities (all cooperative utilities) not making these reports, we relied upon the detailed data files provided by the EIA, recording the responses of utilities to the Annual Electric Power Energy Report (Form EIA-861), which records retail sales by utilities and power marketers (U.S. Energy Information Administration 2023). Two utilities (Dunn Energy Cooperative and Polk-Burnett Electric Cooperative) filled the long version of the form (filled by larger entities), and two (St. Croix Electric Cooperative and Pierce-Pepin Electric Cooperative Services) filled the short form (filled by smaller entities). For our purposes, both the long and short form provided suitable activity information (total energy delivered, total customers) to allocate energy deliveries to counties in concert with Census population data, in the process outlined below.

Because Wisconsin utilities do not report energy deliveries at the county level, it was necessary to estimate energy deliveries by a given utility *i* within a particular county *j.* For those three utilities who reported county-level customer counts and total customer counts to the state, we estimated mWh delivered by utility *i* in county *j* by multiplying their total statewide energy deliveries (as reported to the relevant state authorities) by the proportion of their customers residing in each of our two study area counties.

Note: This approach implicitly assumes that customer accounts across counties within the operations of a given utility have the same average per-account demand for energy, when this is influenced by land-use mix and relative magnitude/scale of residential and commercial/industrial utility accounts within a given county.

To calculate the estimated energy delivered by utility *i* in county *j* for the four cooperatively-owned utilities that did not report county-level customer counts (i.e., did not report to the State), we used population figures to estimate/allocate reported electricity deliveries to counties. We took the actual total energy delivered by utility *i* across Wisconsin (as reported to the relevant federal authorities) and multiplied this by the proportion of total population within each utility’s entire service area residing within county *j* at the 2020 decennial Census.

The factor *ProportionOfTotalUtilityPopulation*j was calculated by spatially joining Census block centroids containing population data to 1) polygons representing the entirety of our in-scope utilities’ service areas (including areas outside of St. Croix and Pierce counties) and 2) polygons representing only the portions of these utilities’ service areas within a) St. Croix county and b) Pierce County. These utility-county service areas are calculated separately, to facilitate an informed allocation of statewide energy use to each county in turn.

#### 5.2.2.1 Correlation with related data

We would expect counties with higher population to have higher emissions.

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| Figure 5.1: County population and electricity emissions |

#### 5.2.2.2 Comparison with federal inventories

##### 5.2.2.2.1 NREL SLOPE

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| Figure 5.2: Metropolitan Council emissions inventory v. NREL SLOPE modeled emissions |

The NREL SLOPE (State and Local Planning for Energy) Platform provides yearly forecasted emissions tied to the user of electricity up to 2050 based on 2016 reported data at the county level. In comparing these figures to our own inventory, we observed that, where we estimated 0 metric tons of emissions linked to electricity deliveries in our study area in the year 2021, NREL SLOPE forecasted 355,545,687metrics tons in our study area.

# 6. Natural Gas

### 6.0.1 Introduction

Greenhouse gas emissions from Minnesota homes and apartment buildings have increased 14% over the past 15 years, and natural gas use is the largest source of these emissions (MPCA 2023). Many local and state governments are evaluating policies to reduce natural gas usage, such as building electrification (when paired with decarbonization of the electric grid) and banning natural gas hookups in new construction.

### 6.0.2 Methods

The general workflow for quantifying natural gas emissions is to identify all of the natural gas utilities that operate within our study area, collect any reporting they provide to the states of Minnesota and Wisconsin about the amount of energy delivered to all their customers, reference federal reporting sources where state-level reporting gaps exist, and apply EPA-provided emissions factors to the reported energy deliveries to calculate emissions. Methodologies for allocating utility activity reports to counties varies across MN and WI and are further described in the following section. All inputs we use in the construction of our natural gas emissions data set are of the highest quality rank ([Table B.2](#tbl-quality-rank)), as they are either direct government-created data (e.g., emissions factors) or data reported to state or federal authorities (e.g., regulatory filings).

Total regional emissions (Emissionsr) represents the sum of all recorded energy deliveries by utility *i* within county *j*, where *i* refers to each of the electric utilities operating across our region, and *j* refers to the eleven counties included in this inventory. Our regional total therefore represents an aggregation of electricity deliveries for all distinct utility-county records within our 11 counties. Our inventory takes a “demand-side” approach to emissions quantification and seeks to aggregate all reported delivery of energy to all customers served by utilities (meaning residential, commercial, industrial, and government accounts).

While our primary data collection does not include a breakout of natural gas deliveries by sector, and represents only *total* natural gas deliveries, we do leverage year 2021 NREL SLOPE forecasts of natural gas consumption (built from a base year of 2016 observed data) by sector (residential, commercial, industrial) at the county level to calculate modeled proportions of consumption by sector, which we then apply to our aggregate numbers to calculate estimated emissions *by sector*. (Ma et al. 2019) (NREL 2017)

#### 6.0.2.1 Identifying utilities in scope

To identify the natural gas utilities that operate within our 11-county study area, we first referred to maps and geospatial datasets capturing utility service areas in Minnesota and Wisconsin. Where possible, state-maintained data sources were used, with federal sources referenced where state sources could not be accessed. To identify Wisconsin gas utilities, we downloaded the Natural Gas Service Territory map maintained by the Wisconsin Public Utilities Commission (Public Service Commission of Wisconsin 2021). Since Minnesota does not publish a state-maintained data set of natural gas service areas (Minnesota IT Services 2021), we used the Department of Homeland Security’s Natural Gas Service Territories map from its Homeland Infrastructure Foundation-Level Data (HIFLD) portal to identify in-scope Minnesota gas utilities (Homeland Security 2017).

#### 6.0.2.2 Collecting and aggregating activity data from utilities

After identifying which utilities operate within our study area within each state, we collected the reporting submitted by these utilities to the relevant state and federal authorities, and followed a distinct process for each state to accumulate data and then allocate energy deliveries to specific counties therein.

##### 6.0.2.2.1 Minnesota

All natural gas utilities authorized to do business in Minnesota are required to file an annual data report pursuant to MN Rules Chapter 7610 (Commerce 2005). The Minnesota Public Utilities Commission makes these reports searchable through an [eFiling Site](https://www.edockets.state.mn.us/EFiling/edockets/searchDocuments.do?method=eDocketsResult&docketYear=22&docketNumber=19) (Minnesota Department of Commerce 2022). For each utility identified in [distinct\_natGas\_util\_MN.RDS](file:///Users/rotenle/Downloads/data/distinct_natGas_util_type_MN.RDS) (a data product of [minnesota\_natGasUtilities.R](file:///Users/rotenle/Downloads/data-raw/minnesota_natGasUtilities.R), a script that looks for intersections between electric utility service areas and our Minnesota counties), we downloaded the relevant annual reports from this site in their Excel workbook form.

We wrote code to extract the county-level data reported in report section “ANNUAL GAS DELIVERED TO ULTIMATE CONSUMERS BY COUNTY IN 2021” from these reports (which were compiled into a distinct folder directory for file processing), and created a table with three columns county, utility, and mcf\_delivered (thousand cubic feet of natural gas delivered). By compiling this data for all utilities found to operate within our study area, aggregating all natural gas deliveries at the county level becomes possible.

##### 6.0.2.2.2 Wisconsin

All municipal and investor-owned natural gas utilities authorized to do business in Wisconsin are required to file an annual report with financial and operational information pursuant to Wis. Stat. § 196.07. The Public Services Commission of Wisconsin makes these reports searchable through an [E-Services Portal](https://apps.psc.wi.gov/ARS/annualReports/default.aspx), and downloadable as either PDFs or Excel workbooks, with options to export only specific portions of the reports as spreadsheets (Wisconsin State Legislature 2024). For each utility identified in [distinct\_natGas\_util\_WI.RDS](file:///Users/rotenle/Downloads/data/distinct_natGas_util_WI.RDS) (a data product of [wisconsin\_natGasUtilities.R](file:///Users/rotenle/Downloads/data-raw/wisconsin_natGasUtilities.R), a script that looks for intersections between electric utility service areas and our Wisconsin counties), we downloaded the relevant 2021 annual reports from this site.

Because of the small amount of data, we hard-coded observed information into data frames rather than extracting data through a web scraper or document analyzer as we did in Minnesota (see [processed\_wi\_electricUtil\_activityData.R](file:///Users/rotenle/Downloads/data-raw/processed_wi_electricUtil_activityData.R).

#### 6.0.2.3 Emissions factors

Natural gas energy deliveries were reported in standard cubic feet and converted into emissions in metric tons CO2e, referencing the 2021 EPA GHG Emissions Factor Hub (USEPA 2021b).

### 6.0.3 Results

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| Figure 6.1: 2021 natural gas emissions |
| Figure 6.2: 2021 natural gas emissions by sector |

#### 6.0.3.1 Correlation with related data

We would expect counties with higher population to have higher emissions.

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| Figure 6.3: County population and natural gas emissions |

#### 6.0.3.2 Comparison with other inventories

##### 6.0.3.2.1 NREL SLOPE

The NREL SLOPE (State and Local Planning for Energy) Platform provides yearly forecasted emissions from natural gas through 2050 based on 2016 observed/reported data at the county level. In comparing these figures to our own inventory, we observed that, where we estimated NA metric tons of emissions linked to natural gas use in our study area in the year 2021, NREL SLOPE forecasted 72,291,521 metric tons in our study area.

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| Figure 6.4: Metropolitan Council emissions inventory v. NREL SLOPE modeled emissions |

# 7. Methods and data sources

## 7.1 Utility Activity Data

### 7.1.1 Minnesota

Under Minnesota Administrative Rules Chapter 7610 (Commerce 2005), utilities are required to file an annual data report that supports the identification of “emerging energy trends based on supply and demand, conservation and public health and safety factors, and to determine the level of statewide and service area needs.” (Minnesota Department of Commerce 2022) This includes a report of county-level energy deliveries (reported in thousand cubic feet, commonly written as mcf). Because the information is structured in this manner, natural gas emissions at the county-level can be estimated as a direct function of energy deliveries to counties reported by utilities, which is not the case in Wisconsin (some modeling and estimation is required in WI).

### 7.1.2 Wisconsin

Under Wis. Stat. § 196.07, investor-owned natural gas utilities operating within the state of Wisconsin must submit annual reports to the State which include an array of information related to utility finance and operations, including key figures leveraged in our data collection, such as total energy deliveries made (in units of *therms*) and total number of customer accounts within each county (Wisconsin State Legislature 2024). Because all four “in-scope” natural gas utilities in Wisconsin are investor-owned, we did not have to refer to federal sources or use population figures to estimate energy deliveries. We estimated county-wide emissions from natural gas in 2021 by first calculating the proportion of each utility customer accounts that were linked to either Pierce or St. Croix counties, and allocating that proportion of the utility’s total reported energy delivery to each county. This approach represents a divergence from our Minnesota process, which involves aggregating county-level numbers directly reported by utilities, and implicitly assumes that customer accounts across counties within the operations of a given utility have the same average per-account demand for energy, when in actuality this is likely impacted by land-use mix and relative magnitude/scale of residential and commercial/industrial utility accounts within a given county.

# 8. Propane and kerosene

[U.S Energy Information Administration](file:///Users/rotenle/Downloads/www.eia.gov) provides per household estimates of residential energy use from residential surveys of propane and kerosene usage patterns and billing data at regional and state scales. These estimates are provided every 5 years, most recently in 2020 (US EIA 2023). [The American Community Survey](https://www.census.gov/programs-surveys/acs), curated by the US Census Bureau, provides the estimated number of households using each fuel type at more granular spatial and temporal scales, including county level estimates in 2021. Energy generation and GHG emissions from these fuels was estimated for each of the 11 counties in our 2021 inventory using these two data sources in combination. Both data sources are from federal governmental agencies, categorized as the highest rank of data quality ([Table B.2](#tbl-quality-rank)).

EIA RECS data was downloaded from their [data portal](https://www.eia.gov/consumption/residential/data/2020/). EIA surveyed 32,882 households nationally for 2020 data and provides estimated mmBtu (millions of British thermal units) generation from propane per household using that fuel at the state level and at the Midwest regional level for kerosene. ACS data was accessed using the tidycensus package in R. ACS conducted 62,778 household interviews in Minnesota in 2021 and provides county estimates of the number of households using a given fuel. Multiplying the estimated mmBtu generated per household in a given region by the county-level estimate of households using the fuel provides a county-level estimate of mmBtu generation from each of propane and kerosene and is then converting to CO2 equivalency using the EPA’s emission factors. This approach assumes energy generation per household per fuel is equal across each state (for propane) and the Midwest region (for kerosene).

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| Figure 8.1: 2021 annual liquid stationary fuel emissions |

# 9. Industrial

## 9.1 Introduction

Industrial facilities are major emitters stemming from high electricity demand, on-site fuel combustion, and industrial processes. The data presented here are aggregations of industrial point source reporting to state and federal agencies. Care must be taken to avoid double-counting in this sector, as industry includes emissions from power plants, waste facilities, and natural gas combustion that can be counted in other sectors. Natural gas combustion is the most difficult class to account for, as natural gas is delivered both within and without the services of utilities. Our analysis assumes (and thus omits) all natural gas combustion reported to EPA and MPCA are utility sourced except for the two refineries in boundary, which appear to have direct natural gas pipeline access. Smaller emitters are not required to report to state and federal agencies, meaning a small but potentially significant slice of industrial emissions may be missing, though any natural gas combustion is likely to be included in our utility demand analysis.

The results presented in this section are therefore emissions from major industrial point sources NOT including energy supplied from electric and natural gas utilities.

## 9.2 Results

### 9.2.1 2021 county and subsector breakdown

Industrial point-source emissions (i.e. excluding electricity usage and utility provided natural gas) accounted for 11.8% of total emissions in the 11-county region in 2021. County emissions vary widely due to the point source approach of industrial emissions, as opposed to the demand-side approach of electricity, residential building fuel, waste, and functionally on-road transportation. The largest example is that two in-boundary oil refineries account for 80.4% of point-source industrial emissions in 2021.

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| Figure 9.1: 2021 county industrial emissions |

### 9.2.2 Baseline emissions

Regional industrial emissions have increased by 28% since 2005, although emissions prior to 2011 are modeled by anchoring to MN Pollution Control Agency industrial emissions, which may or may not adequately represent metro region emissions. Emissions compared to 2011, the earliest year of federally supplied GHG data, there is a much more modest observed increase of 2.7%.

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| Figure 9.2: Baseline industrial emissions |

### 9.2.3 Emissions by gas type

Industrial emissions are varied, including carbon dioxide, methane, nitrous oxide, and a variety of fully fluorinated gases from industrial processes.

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| Figure 9.3: 2021 county agricultural emissions by gas type |

### 9.2.4 Scaling to CTUs

As industrial emissions are provided as point sources, scaling to cities is already done. Note that the color ramp in the map below is on a log scale due to the oil refinery in Rosemount - pop-up values are reported as untransformed values, however.

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| Figure 9.4: 2021 city level industrial emissions |

# 10. Methods and data sources

##Summary Industrial emissions are derived from MN Pollution Control Agency (MPCA) fuel combustion data and from two EPA sources: the Greenhouse Gas Reporting Program (GHGRP; via FLIGHT: Facility Level Information on GHG Tool) and the National Emissions Inventory (NEI). These datasets have strengths and limitations which complement one another. The MPCA data has smaller facilities and commercial fuel combustion, but dates back only to 2016. GHGRP has facility source data dating back to 2010, but only facilities with 25,000+ metric tons of annual CO2e emissions are required to report to this program. The NEI aggregate county data includes smaller facilities, but only has GHG emission estimates for 2017 and 2020 and lacks the source level specificity. Additional data resources may be available via the federal US Energy Information Administration datasets.

## 10.1 Double counting

A key concern for industrial emissions is avoiding double counting, particularly natural gas combustion, electricity generation, and waste management. Our energy analysis uses a demand side approach to allocate electricity usage and natural gas combustion to residential, commercial, and industrial sectors. For electricity, this means avoiding industrial emissions that arise from electricty generation (note GHGRP and NEI already avoid counting electricity consumption at industrial facilities in their analyses). Natural gas consumption requires greater care, as combustion for industrial units (e.g. boilers) may be one of or some combination of natural gas, petroleum products, coal, or other fuel sources; additionally utility provisioning of natural gas may not account for all natural gas combustion at industrial sources. Our current approach assumes only the two major refineries in-bounds have natural gas access outside of the utilities; thus all other natural gas combustion reported by industrial point sources are assumed to be counted in utility reporting. We explore this below. Our waste sector accounts for municipal waste emissions, though it does not inventory industrial waste processing.

## 10.2 Electricity generation

Electricity generation is indicated as industrial subpart “D”, and can be omitted from GHGRP data easily. Note that power plants also have some fuel combustion that are not directly for electricity generation and it is currently unclear if that is accounted for in our egrid analysis. However, in NEI data, powerplants are grouped under NEC (Not Elsewhere Classified), which includes non-powerpoint sources, requiring care to avoid double-counting (e.g. subtracting away GHGRP power plant data)

## 10.3 Natural gas

Detailed data can be found in the GHGRP, particularly for fuel combustion. That allows us to subtract away natural gas combustion emissions from industrial combustion, to avoid potential double counting of natural gas utility data. Note that further inquiry is required to ensure that industrial natural gas is provisioned by the utilities. An additional subpart that requires investigation is “Y” which includes flaring data, which is often flaring of natural gas. MPCA data separates gas consumption for flaring.

## 10.4 Waste

We are omitting in-bound municipal waste facilities from our industrial analysis to avoid double counting with our waste emissions analyses (based on county waste volume in Minnesota). Industrial waste facilities will be analyzed here.

# 11. Data source comparisons

Due to the reasons listed above, the expectation should be that MPCA (smaller facilities, no process emissions), GHGRP (only larger facilities), and NEI (all facilities, no point source specificity means double-counting) provide substantially different values.

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| Figure 11.1: Comparison of 2020 industrial emissions from FLIGHT, MPCA, NEI |

Currently, we are seeing large deviations (high and low) between MPCA data and federal sources, particularly in Dakota (Refinery) and Hennepin counties. MPCA data only accounts for fuel combustion, not process emissions that are common from semi-conductor manufacturing in Hennepin.

Currently, GHGRP and MPCA data can be reliably used to avoid double-counting by avoiding emissions from Natural Gas. We can compare how subpart C (Industrial combustion) analyses compares to facilities with only subpart C FLIGHT aggregates. This includes natural gas doublecounts, but validates that our subpart C analysis accurately recaptures EPA aggregated FLIGHT emissions .

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| Figure 11.2: Comparison of industrial combustion emissions from FLIGHT and subpart C analysis |

Most emissions are on or sufficiently close to the one-to-one line. The exception is the Hennepin Energy Recovery Center, a waste burning facility. This requires further exploration but will be omitted in any case as waste-to-energy emissions are counted in the waste subsector.

# 12. Natural Gas

Given overall compliance between our subpart C analysis and EPA reporting, natural gas combustion was pulled out from MPCA and subpart C analyses for non-refinery industries and compared to our estimates of utility-supplied natural gas deliveries to the industrial sector (via NREL). Generally it looks like NREL greatly over-apportions natural gas consumption by industrial sources in all counties, and may include refinery natural gas consumption in Dakota and Washington. Future analysis will looks at utility breakdowns of natural gas delivery to utilities as a more accurate apportionment.

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| Figure 12.1: Comparison of natural gas combustion data |

### 12.0.1 Scaling to CTUs

Industrial emissions are provided as point sources from federal and state databases, allowing straightforward attribution to cities and townships. One remaining issue is to ensure proper attribution for cities and townships that share a name.

# 13. Waste and wastewater

## 13.1 Introduction

In 2021, waste activities over the entire United States generated emissions of 169.2 MMTCO2e, or 2.7 percent of total U.S. greenhouse gas emissions (USEPA 2023b). In the 11-county Twin Cities MSA region, municipal waste produced 1.813329 MMTCO2e, or 3.5% of the regional total.

Municipal waste can broadly be divided into biogenic wastewater emissions and solid waste emissions. Our inventory accounts for industrial waste emission point sources in the industrial sector and wastewater processing emissions such as electricity and transportation in their respective sectors. Note that the Metropolitan Council Climate Action Work Plan accounts for holistic operational inventory emissions from wastewater processing.

## 13.2 Results

### 13.2.1 Baseline emissions

Regional waste emissions have increased by 6.94% since 2005, likely tied to population growth despite successful measures to reduce emissions per capita.

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| Figure 13.1: Baseline agricultural emissions |

### 13.2.2 Emissions by gas type

The majority of waste emissions by weight are CO2, but when accounting for the increased warming potential of methane, CO2e, methane contributes the most to global warming. CO2: 20% CH4: 69.7% N2O: 10.3%

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| Figure 13.2: 2021 county waste emissions by gas type |
| Figure 13.3: 2021 county waste emissions by gas type - CO2e |

### 13.2.3 Solid waste

#### 13.2.3.1 2021 emissions

Solid waste generated 1.48 MMtCO2e of emissions in the Twin Cities MSA in 2021. Of that total, 59.7% of emissions came from landfill, 25.0% from waste to energy facilities, and the remaining 15.3% from organics and onsite.

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| Figure 13.4: 2021 solid waste emissions |

Greenhouse gas emissions from solid waste are dominated by the landfill sector. In Hennepin, Ramsey, and Washington counties, municipal centers where a significant portion of waste is incinerated, waste-to-energy or incineration makes up a large fraction of emissions as well.

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| Figure 13.5: 2021 solid waste emissions by category |

#### 13.2.3.2 Historical emissions

The variation of solid waste emissions over the past 16 years is mainly due to variations in amount of waste collected. It does not take into account changes in methane capture and removal technology or adoption.

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| Figure 13.6: Solid waste emissions by county, 2005-2021 |
| Figure 13.7: Solid waste emissions by source, 2005-2021 |

# 14. Methods and data sources

# 15. Solid waste

## 15.1 Methods

Solid waste emissions for Minnesota and Wisconsin are calculated using two different methods due to a difference in data availability.

### 15.1.1 Minnesota

The previous iteration of this inventory calculated Minnesota’s solid waste emissions by multiplying activity totals by emissions factors from the EPA’s Emissions Factor Hub. This update instead uses methodologies recommended by the Intergovernmental Panel on Climate Change (IPCC) (“2006 IPCC Guidelines for National Greenhouse Gas Inventories” 2006).The methodologies were selected to align with best practices for community-wide inventories using the IPCC recommendations and the guidance of the Global Protocol for Community-Scale Greenhouse Gas Inventories (Fong et al. 2021).

#### 15.1.1.1 Landfill

The IPCC suggests two alternatives for calculating landfill emissions, a first order decay model and a methane commitment model. The first order decay model is often used for larger-scale inventories, such as the US Federal Inventory, and requires waste data going back to 1950. Given the data available and the scope of this inventory, we chose to instead use the simpler methane commitment model to calculate county-level emissions for Minnesota.

The methane commitment model calculates methane emissions from landfills for a given year by multiplying municipal solid waste totals by a methane generation potential and adjusting for oxidation and methane flaring,

, or the amount of municipal solid waste processed in landfills, is reported on a county level by MPCA’s SCORE report (**?@sec-mpca-score**).

It is then multiplied by a methane generation potential . In some processes, the amount of methane recovered from landfills, either through methane flaring or landfill gas to energy programs, is subtracted here. Due to data concerns and best practices recommendations, we have chosen not to include methane recovery in our Minnesota emissions calculations. Learn more in [Section 15.2.5](#sec-epa-methane).

After subtracting methane recovered, emissions are multiplied by to account for oxidation in the landfill. Our oxidation value is assigned the IPCC default of 0.1.

, the methane generation potential, is calculated as follows:

where

* = methane commitment factor. Assigned IPCC default of 0.5 for managed, semi-aerobic landfills.
* = fraction of degradable organic carbon degraded. Assigned IPCC default of 0.6.
* = fraction of methane in landfill gas. Assigned IPCC default of 0.5.
* = Methane (CH4) to carbon (C) ratio (atomic weight)
* = degradable organic carbon. Calculated based on local waste makeup data from MPCA’s [2013 Statewide Waste Characterization study](https://www.pca.state.mn.us/sites/default/files/w-sw1-60.pdf), using the equation .

#### 15.1.1.2 Compost

Compost produces both methane and nitrous oxide. Emissions are calculated by multiplying waste activity totals by emissions factors divided between aerobic and anaerobic digesters. Since Minnesota only has one anaerobic digester that is outside the inventory area, we assumed 0% anaerobic digestion within the inventory area (source).

As in other sections, MSW activity data comes from MPCA’s SCORE report. The emissions factors of 10 and 0.6 come from IPCC default values.

#### 15.1.1.3 Incineration

Since incineration data is reported to SCORE as Waste to Energy, it is assumed that all incineration in the MSA is considered Waste to Energy.

Incineration of waste produces CH4, CO2, and N2O emissions. However, the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories reports negligible CH4 emissions for continuous incineration facilities.

where:

* = municipal solid waste incinerated, as reported by SCORE.
* = efficiency of combustion for incineration. Assigned IPCC default of 95%.
* = municipal solid waste burned onsite, as reported by SCORE.
* = efficiency of combustion for onsite burning. Assigned Greenhouse Gas Protocol default of 71%.
* = fraction of carbon content in MSW. Assigned IPCC default of 40%.
* = fraction of fossil carbon in MSW. Assigned IPCC default of 40%.
* = Ratio of carbon dioxide (CO2) to carbon (C) by atomic weight
* = aggregate N2O emission factor for MSW. Assigned GHG Protocol default of 50 g N2O/ metric tons waste for continuous and semi-continuous incinerators.

#### 15.1.1.4 City-level estimates

Given that the most granular solid waste data available is at the county level, waste emissions estimates are allocated to cities by population. County emissions are multiplied by the city or municipality’s share of county population.

This means that city-level estimates do not account for differences in waste collection programs between cities. The data may, for example, allocate organics emissions to cities that do not have organics processing programs. For this reason, we do not provide a breakdown of city-level emissions by source, and instead use only the total solid waste emissions. This should provide a relatively accurate estimate of total solid waste emissions for your community.

#### 15.1.1.5 Limitations

Because the methane commitment method for landfill emissions calculates emissions slightly differently than the IPCC-encouraged First Order Decay model, landfill results may differ slightly from sources that use First Order Decay, such as the EPA’s National Inventory and its State Inventory Tools. Both methods are accepted as valid ways to estimate solid waste emissions.

MPCA SCORE does not report activity data for waste generated and processed by industry.

Emissions are not calculated for waste that is recycled, as any emissions generated in the recycling process come from the energy use of the facilities or transportation and are accounted for in other sectors of this inventory.

### 15.1.2 Wisconsin

Wisconsin emissions are calculated by interpolating and scaling down state-level data from the Wisconsin DNR (Wisconsin DNR 2021).

This 2021 inventory estimates landfill and waste-to-energy emissions for the years 2005 and 2018, including methane recovery offsets. In order to fill in missing years, emissions between 2005 and 2018 were linearly interpolated. Due to the small amount of change in emissions, it was assumed that emissions from 2018 to 2021 were constant. These emissions were then allocated to counties based on population.

## 15.2 Data sources

### 15.2.1 MPCA Waste Characterization Study

In 2013, the MPCA contracted with Burns & McDonnell Engineering Company, Inc. to conduct a waste characterization study of landfill waste, an update to an earlier study in the year 2000. For simplicity, we have chosen to set waste proportions equal to those 2013 values for all years in this inventory.

The study sampled waste makeup from six waste disposal facilities across the state and used the results to model statewide totals. More details can be found in [study documentation](https://www.pca.state.mn.us/sites/default/files/w-sw1-60.pdf).

This data is a high-quality state-level dataset.

For consistency, the values in this study have been compared to the IPCC default waste breakdown for North America. Relevant values were found to be consistent within 90% confidence intervals (as reported in the MPCA study), with the exception of food waste. IPCC values attribute 33.9% of landfill waste to food waste, while the 2013 report only finds that 17.8% of landfill waste is food waste. There are many possible explanations for this discrepancy, including differences in waste breakdown across the North American region and the possibility that the IPCC’s numbers reflect additional food waste processed in organics facilities, which would not be included in the MPCA study.

Due to the fact that it is more recent and more specific to the Minnesota region, we have chosen the MPCA study as the source of truth in this case.

### 15.2.2 Wisconsin Greenhouse Gas Emissions Inventory

Waste emissions for Wisconsin counties were unavailable in the same detail as the MPCA data. Thus, we estimated total waste emissions based on statewide emissions estimates, allocated by population.

The most recent [Wisconsin Greenhouse Gas Emissions Inventory](https://widnr.widen.net/view/pdf/o9xmpot5x7/AM610.pdf?t.download=true) was done in 2021 by the Wisconsin Department of Natural Resources. Included in the solid waste data for this source are emissions from landfills and waste combustion, taking into account the emissions reduced by landfill gas collection for gas-to-energy use or flaring. This inventory does not, however, include emissions generated from composting or recycling.

The emissions for solid waste in this report were calculated using the [EPA’s State Inventory and Projection Tool](https://www.epa.gov/statelocalenergy/state-inventory-and-projection-tool), a tool designed to help states calculate greenhouse gas emissions (USEPA 2024a). Default values provided by the tool were used except in the case of default Mixed Solid Waste population tonnage values, which were replaced by data from the Wisconsin state DNR Annual Waste Tonnage Report (Wisconsin DNR 2021).

For 2018, the Wisconsin DNR reported 2.2 million metric tons carbon dioxide equivalent (MMTCO2e) generated through landfilling and solid waste management.

In the process of analysis, this statewide estimate was apportioned to the county level based on county population data, as detailed in [Chapter 14](#sec-waste-methods).

### 15.2.3 Limitations

* Since data reported directly from the counties was unavailable for Wisconsin, the solid waste data used here reflects a disaggregation of state-level data and may not be reflective of the specific mix of waste generated by Pierce and St. Croix counties.
* Data collected in Wisconsin’s emissions inventory only represents waste disposed of in landfills or waste combustion facilities, and does not include organics. Composting data is unavailable for Wisconsin counties.

### 15.2.4 Comparison to similar datasets

The US EPA completes yearly state-level estimates of emissions for each state, which combined sum to the totals reported in the US Greenhouse Gas Emissions Inventory. The data for these estimates and the US inventory can be explored at the [GHG Inventory Data Explorer](https://cfpub.epa.gov/ghgdata/inventoryexplorer/index.html). The EPA’s total of landfill emissions for Wisconsin for 2018 was 2.450 MMTCO2e, not far off from the Wisconsin DNR’s 2.2 MMTCO2e. The EPA’s estimate for 2021 was 2.422 MMTCO2e. More details can be found in [Section 17.2](#sec-waste-inventory-comparison).

Since the EPA completes an inventory for the entire US and its methods may not reflect the specific nuances of emissions in each state, we elected to use the data from the Wisconsin DNR for this inventory.

### 15.2.5 EPA Methane Recovery Data

The EPA generates methane flaring and landfill gas to energy data for each state as part of its State Inventory Tool for solid waste. This data is collected as part of the [Landfill Methane Outreach Program](https://www.epa.gov/lmop).

However, since this data is collected on a national level, there are potential discrepancies with state-level and especially regional breakdowns of methane recovery. Due to these concerns, we have chosen to exclude this data source from our inventory and instead use the IPCC default of 0 methane recovery. This means that our inventory may overestimate emissions from solid waste landfills.

# 16. Wastewater

## 16.1 Methods

## 16.2 Data sources

# 17. Data Validation

## 17.1 Correlation with related data

We would expect counties with a higher population to have higher solid waste emissions.

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| Figure 17.1: County population and solid waste emissions |

## 17.2 Comparison with other inventories

### 17.2.1 US Greenhouse Gas Emissions Inventory

The United States EPA conducts a comprehensive yearly estimate of greenhouse gas emissions from multiple sectors and gases. It also publishes statewide totals consistent with the national inventory. These emissions totals are consistent with international standards for greenhouse gas accounting, although they may differ from inventories completed at the state level for various reasons.

US Inventory data for the waste sector in both Minnesota and Wisconsin was downloaded from the [Greenhouse Gas Inventory Data Explorer](https://cfpub.epa.gov/ghgdata/inventoryexplorer/) and processed in R script: [epa\_inventory\_data.R](file:///Users/rotenle/Downloads/data-raw/epa_inventory_data.R), where it was apportioned from state to county level by population.

Here, we compare federal inventory data with our current data as well as a previous version of the Met Council inventory, which instead of using IPCC protocols multiplied SCORE data by the EPA’s emission factors.

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| Figure 17.2: Solid waste emissions comparison: US GHG Inventory |

# 18. Agriculture

## 18.1 Introduction

Agricultural systems are major emitters of methane and nitrous oxide, both from livestock and croplands. Livestock emissions come primarily from enteric fermentation, the formation of methane in ruminants stomachs during digestion, and secondarily from manure emissions of both methane and nitrous oxides. Cropland emissions are predominantly nitrous oxide that is formed from biogeochemical processes related to crop-soil interactions and the direct application of synthetic fertilizers. Carbon dioxide emissions are a smaller share of agricultural emissions, arising predominantly from operation of agricultural equipment, liming of soils, and production of urea used for fertilizer.

## 18.2 Results

### 18.2.1 2021 county and subsector breakdown

Agriculture accounted for 2.2% of total emissions in the 11-county region in 2021. As expected, more rural counties produce a larger share of the agricultural emissions, with St. Croix, Pierce, Dakota, and Carver accounting for 77.1% of the regions agricultural emissions.

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| Figure 18.1: 2021 county agricultural emissions |

### 18.2.2 Baseline emissions

Regional agricultural emissions have decreased by 0% since 2005, potentially reflecting increased agricultural abandonment and suburban expansion in the region.

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| Figure 18.2: Baseline agricultural emissions |

### 18.2.3 Emissions by gas type

The majority of agricultural emissions by weight are methane, but when accounting for the increased warming potential of nitrous oxide, CO2e the two are roughly equivalent. CH4: 48.2% N2O: 51.8%

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| Figure 18.3: 2021 county agricultural emissions by gas type (CO2e) |

## 18.3 CTU Estimates

Agricultural emissions are apportioned to cities and townships in two ways. First, county crop production and fertilizer application are apportioned to cities and townships by their percentage of the counties cropland acreage. Second, livestock are assumed to have minimal occurrences in city boundaries, so the headcounts are apportioned to only townships by their proportional cropland acreage (in Hennepin, where there are no townships, we instead include only cities with more than 10 square kilometers of cropland). Based on these activity data, we follow the same emission calculations as for counties.

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| Figure 18.4: 2021 city level agricultural emissions |

## 18.4 Summary

Methane production is largely tied to consumer food preferences, with enteric fermentation in cattle raised for meat and dairy production being the central driver of agricultural methane production. Nitrous oxide emissions also derive from livestock via manure emissions, both in managed systems and in manure that is applied to or leaches into soils. Crop production also accounts for a large percentage of agricultural nitrous oxide emissions via synthetic fertilizer production and the biochemical processes that delivers nitrogen to soils. Efficient agricultural techniques, particularly in crop management, can reduce the amount of nitrogen entering soil and therefore the amount that is volatilized into gaseous nitrous oxide.

# 19. Methods and data sources

Agricultural emissions are derived from two primary sources. First is the USDA agricultural census which provides county level livestock head counts, crop production, and fertilizer sales. Second is the EPA State Inventory Tool (SIT) that provides state specific values for emission factors as well as activity data such as state-wide fertilizer application (different from sales). These are both the highest rank of data.

The USDA census is conducted once every five years (years ending in ’2 and ’7). For interstitial years we used linear interpolation to provide county level estimates.

The SIT provides guidance on how to translate livestock counts, crop production, and fertilizer use into emission factors. A brief description of the major emitters in this sector is listed here, but please refer to the SIT documentation for more detail information.

# 20. Livestock

## 20.1 Enteric fermentation

Enteric fermentation is methane emitted from livestock during digestion.

## Manure management

Manure in lagoons and holding facilities emits methane and nitrous oxide. Both gaseous emissions depend on the amount of volatile solids produced by livestock and the management regimes, both of which vary by livestock type. Adult cattle volatile solids are calculated using a variable based on heads of cattle; other livestock (including cattle calves) volatile solids are calculated based on animal mass, which is itself calculated by multiplying number of livestock by the typical animal mass of that livestock type.

Methane emissions are calculated as follows:

where *i* represents livestock from the following categories: Dairy Cows, Beef Cows, Feedlot Cattle, Calves, Swine, Sheep, Goats, Chickens (Broilers, Pullets, and Layers), and Turkeys.

Nitrous oxide emissions are calculated as follows:

where *i* represents livestock from the following categories: Dairy Cows, Beef Cows, Feedlot Cattle, Calves, Swine, Sheep, Goats, Chickens (Broilers, Pullets, and Layers), and Turkeys; and *j* is dry or wet manure management systems. In other words, total nitrous oxide emissions are the sum of manure managed in wet systems or dry systems, each of which have different emission factors. EPA assumes no nitrogen is volatilized prior to storage (i.e. Volatilization Percent is 0 in the above equation).

## 20.2 Manure runoff

Manure from managed and unmanaged systems enter soil via application or runoff and cause additional nitrous oxide emissions.

Indirect manure runoff emissions also occur when unvolatilized nitrogen runoff and later volatilizing on or off site. It is calculated as:

where EPA provides an estimate of volatilization percent of 0% (i.e. all volatilization occurs after manure runoff) and a leaching percent of 30%.

There are also direct nitrous oxide emissions from manure applied to soils as fertilizer or manure left on soils in pasture. Manure applied to soils is calculated as:

where *i* is the livestock type. EPA provides estimates of 20% for Indirect Volatilization Percent, 0.0125 as the non-volatized EF, and 1.571 is the ratio of nitrous oxide to N\_2\_.

Manure left on soils in pasture emissions are calculated as:

where *i* is the livestock type. EPA provides an EF of 0.02 for manure on pasture soils and 1.571 is the ratio of nitrous oxide to N\_2\_.

The SIT calculates emissions by multiplying each animal population (entered in the manure management worksheet) by the rate of N excreted by animal type, provided in kg/head/year for cattle (excluding calves), and kg/1,000 kg animal mass/day for calves and all other livestock (i.e., swine, poultry, sheep, goats, and horses). For cattle (excluding calves), animal population is multiplied by the K-nitrogen excretion rate (kg/head/year) for total K-nitrogen excreted. For calves and all other livestock, animal population is multiplied by the TAM (kg), the K-nitrogen excretion rate (kg/1,000 kg animal mass/day), and 365 days per year for total K-nitrogen excreted. Next, the total K-nitrogen is disaggregated into manure handled in managed systems, manure applied as daily spread, and manure deposited directly into pastures, ranges, or paddocks, based on default percentages obtained from the U.S. Inventory (EPA 2023a). Direct emissions from manure handled in management systems and applied as daily spread is multiplied by the volatilization factor (0.8) to obtain the total unvolatilized N. Additionally, for poultry an adjustment must be made for the small portion of waste used as animal feed. For all poultry categories (i.e., layers (hens, pullets, and chickens), broilers, and turkeys), the total K-nitrogen in managed systems is multiplied by 0.958, as it is assumed that 4.2 percent of all poultry manure is used as animal feed and not applied to agricultural soils (Carpenter 1992). The total unvolatilized N is multiplied by the emission factor for direct emissions of N2O (1.0 percent) to obtain the amount of emissions in N2O-N/yr. For animal waste deposited directly onto pasture, range, and paddock the total K-nitrogen is multiplied by the percent of manure deposited on pasture, range, and paddocks and the IPCC default emission factor for direct emissions (0.02 kg N2O-N/kg N excreted) (IPCC 1997, EPA 2023a) to obtain the amount of emissions in N2O-N/yr.

# 21. Cropland -

## 21.1 Plant residue

Croplands emit nitrous oxide via legumes (i.e. soybeans, alfalfa, beans) that fix atmospheric N2 in the soil, some of which is converted to nitrous oxide via soil biochemical processes. Additionally, non-legume crops have residues that are left on soils and breakdown into the soil, emitting further nitrous oxide.

### 21.1.1 Legumes:

Emissions (MTCO2E) = Crop Production (MT) × Mass ratio (residue/crop) × Dry Matter Fraction × N content × Emission Factor (1.0%) × 44/28 (Ratio of N2O to N2O-N)

### 21.1.2 Residues:

Emissions (MTCO2E) = Crop Production (MT) × Mass ratio (residue/crop) × Dry Matter Fraction × Fraction Residue Applied × N content × Emission Factor (1.0%) × 44/28 (Ratio of N2O to N2O-N)

## 21.2 Fertilizer application

Synthetic and organic fertilizers breakdown to provide N to crops, but some fraction of this is converted to nitrous oxide that is emitted to the atmosphere.

### 21.2.1 Direct

Emissions (MMTCO2E) = Total N × fraction unvolatilized (0.9 synthetic or 0.8 organic) × 0.01 (kg N2O-N/kg N) × 44/28 (Ratio of N2O to N2O-N) × 265 (GWP) ÷ 1,000,000,000 (kg/MMTCO2E)

### 21.2.2 Indirect

Emissions (MMTCO2E) = Total N × fraction volatilized (0.1 synthetic or 0.2 organic) × 0.001 (kg N2O-N/kg N) × 44/28 (Ratio of N2O to N2O-N) × 265 (GWP) ÷ 1,000,000,000 (kg/MMTCO2E)

## 21.3 Fertilizer runoff

Some proportion of applied fertilized is leached into the soil and runs off into streams and adjacent soils, where it further is chemically converted to nitrous oxide.

### 21.3.1 Remaining work

## 21.4 Missing data

The USDA census program does not report data in counties having less than a minimum number of operations. This most notably affects Ramsey County in our inventory, and subsequently the cities within the county. A potential future fix is to model livestock, crop yield, and fertilizer purchases based off of operational data (which is reported) from within Ramsey and other counties.

## 21.5 Missing subsectors

Small emission sources not currently accounted for: liming, indirect N2O from livestock/soils-animal sheet, residue burning.

## 21.6 Potential errors

Calculation fixes - Fertilizer runoff (from ag soils-animals) sheet is currently calculated from total fertilizer but should only be from volatized, leading to a likely small over estimation.

Be sure to add a citation of this dataset to the Zotero shared library.

## 21.7 Data validation

### 21.7.1 Emissions vs. agricultural lands

We would expect that counties with higher amounts of agricultural land would have higher emissions associated with crop production and likly livestock, though the latter may be more poorly predicted as area required for livestock can vary greatly depending on management.

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| Figure 21.1: Cropland by agricultural emissions comparison |

As expected, we see that livestock and crop emissions increases with area devoted to agriculture. There is potentially a non-linear relationship with livestock, with smaller agricultural areas less likely to have large livestock populations, making the fit more tenuous for these counties.

### 21.7.2 USDA cattle census vs annual surveys

Most USDA data is available from a five year census; we interpolate

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| Figure 21.2: Comparison of heads of cattle - USDA Census vs Survey |

Estimates from the census and surveys are reasonably close for dairy cows and beef cows, the former which are the biggest emitters. For calves, there is increasing disagreement between the survey and census at large head counts, with the census typically estimating lower head counts for both interpolated and actual census years. We will continue using the census head count data as it’s error is likely less and it contains non-cattle animal counts.

### 21.7.3 Scaling to CTUs

In the absence of CTU level livestock or crop production data, the ICLEI U.S. Community Protocol recommends downscaling from county data using the ratio of agricultural land in the community to agricultural land in the county. We followed this approach for downscaling county level emissions using NLCD land cover data to find the ratio of CTU agricultural land to county agricultural land. Future work should seek to downscale livestock counts and crop production (i.e. activity data) and recalculate emissions, enabling more direct reduction measure estimations for various agricultural components (e.g. changes to cattle feed additives that may reduce enteric fermentation).

# 22. Natural Systems

## 22.1 Introduction

Natural systems are a critical component of capturing carbon from the atmosphere and sequestering it in biomass and terrestrial soils. Photosynthesis is the central mechanism of this process and vegetation is therefore the focal land cover classification for quantifying the potential for regions to both sequester and store carbon. Different ecosystems have varying capacities for carbon capture and this work focuses on five broad classifications: urban trees, urban grasslands (i.e. turf grass, lawns), forests, natural grasslands, and wetlands. The distinction between tree and grassland cover in developed areas (i.e. urban) is important as despite having similar sequestration rates, urban natural systems are generally understood to have smaller storage capacities. The preservation and restoration of natural systems will be a key tool in reducing atmospheric greenhouse gases.

## 22.2 Methods

The approach for calculating carbon sequestration potential for a given geography, , is,

where is land cover classification. The sequestration rate is based on Midwest specific sequestration rate estimates found in the primary scientific literature (**?@tbl-sequestration**).

### 22.2.1 Land cover classification

Land cover was determined by using two products from the [USGS’s National Land Cover Dataset (NLCD)](https://www.usgs.gov/node/279743), each at a 30 m resolution: (1) land cover type and (2) percent tree canopy cover. First, we used the land cover map to identify the region’s various natural cover types (e.g. forests, wetlands, grasslands) that fell outside of ‘Developed’ lands. In order to classify green spaces that are co-located within the urban sector (e.g. urban trees and grasslands), we overlaid the tree canopy cover map on the land cover map. When tree canopy was present in any areas classified as ‘Developed’, we re-classified these as ‘Urban\_Tree’ and corrected the area covered based on the percent tree canopy value from the NLCD tree layer. When an area is classified as ‘Developed, Open Space’ but contains zero tree canopy coverage, we re-classified this as ‘Urban\_Grassland’. Using this method, we developed the following land cover classifications: ‘Urban\_Tree’, ‘Urban\_Grassland’, ‘Tree’, ‘Grassland’, and ‘Wetland’.

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| Figure 22.1: USGS National Land Cover Database (NLCD) - Land Cover Types |
| Figure 22.2: USGS National Land Cover Database (NLCD) - Tree Canopy Cover |

## 22.3 Results

There is considerable variation across counties in two key components that affect natural system carbon sequestration and stock potential: total area of green spaces and the ratio of ‘natural’ to ‘urban’ green spaces. For example, Chisago County features a higher proportion of green spaces in undeveloped lands compared to Hennepin County, and consequently has nearly 40% greater stock potential than Hennepin County owing to the former’s higher stock capacity in wetlands and forests. Despite this discrepencancy, Hennepin and Chisago Counties have nearly identical sequestration rates due to Hennepin County’s high proportion of urban trees and turf grass (urban grasslands) which have high potential for rapid carbon sequestration. This dichotomy illustrates that different counties curation of natural spaces may play different roles. Highly developed areas may help offset carbon emissions by providing rapid sequestration sinks in urban greenery, whereas less developed counties can provide longer term carbon sinks in natural areas with a higher capacity to continue drawing down atmospheric carbon even if future emissions approach net zero. The high stock capacity also reinforces the need for natural systems protection, as currently captured carbon would be released into the atmosphere upon development.

Two important caveats to these results are that (1) carbon sequestration tends to slow as natural systems mature and (2) present day natural systems exist at some intermediate level of the illustrated carbon stock potential. The former means that these approximations could be higher or lower depending on the average age of natural systems in each county (e.g. time since agricultural abandonment). The latter means that the loss of these natural systems to development or habitat instruction means that not only would the region lose carbon sinks, but a substantial amount of the stored carbon will be transferred to the atmosphere, increasing atmospheric greenhouse gases.

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| Figure 22.3: 2021 county natural system carbon stock potential |

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| Figure 22.4: 2021 county natural system carbon sequestration potential |

### 22.3.1 Correlation with county area

The expectation is that larger counties have higher carbon sequestration and storage capacities due to more acreage for green spaces; this is indeed observed.

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| Figure 22.5: 2021 carbon stock by county area |
| Figure 22.6: 2021 carbon sequestration by county area |

### 22.3.2 Regional parks

Parks play an important role in climate change resilience by protecting existing natural systems and acquiring lands for natural system restoration. The regional park system of the seven county Twin Cities region provides an excellent example of this. The following graphs show how regional parks, on a per area basis, are more efficient carbon sinks than the counties they reside in. For both sequestration and stock potential, this is in large part due to a much small proportion of non-green spaces (e.g.. impervious surfaces, agricultural lands), but stock potential in particular has a higher capacity due to a larger proportion of natural green spaces as opposed to urban green spaces. Regional parks represent 4.0% of the total land area of the seven county region, but 5.1% of its carbon sequestration potential and 6.3% of its carbon stock potential.

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| Figure 22.7: 2021 comparison of carbon stock per square kilometer in counties and regional parks |
| Figure 22.8: 2021 comparison of carbon sequestration per square kilometer in counties and regional parks |

# Appendix A — Supplementary data

## A.1 Emissions factors

Note for solid waste, the global warming potentials used to calculate CO2e are sourced AR4, not AR5, like the rest of our inventory. However, documentation for the EPA WARM tool (USEPA 2019), indicates that the differences in total CO2e emissions is negligible.

All EPA Emission Factor Hub values were pulled from an Excel workbook downloaded from the EPA website. Values were processed in [epa\_ghg\_factor\_hub.R](file:///Users/rotenle/Downloads/data-raw/epa_ghg_factor_hub.R).

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| Table A.1: Electricity emission factors. 2021 EPA GHG Emission Factor Hub, EPA eGRID2019, February 2021.   | eGrid Subregion | Grid Output | GHG | lb GHG per MWh | | --- | --- | --- | --- | | MROW (MRO West) | Total output | CO₂ | 995.80000 | | MROW (MRO West) | Total output | CH₄ | 0.10700 | | MROW (MRO West) | Total output | N₂O | 0.01500 | | MROW (MRO West) | Total output | CO₂ | 1821.84000 | | MROW (MRO West) | Total output | CH₄ | 0.02800 | | MROW (MRO West) | Total output | N₂O | 0.03071 | |
| Table A.2: Stationary combustion emission factors. 2021 EPA GHG Emission Factor Hub, Federal Register EPA; 40 CFR Part 98.   | Fuel type | GHG | GHG Quantity | Unit | Value | | --- | --- | --- | --- | --- | | Natural Gas | | | | | | Natural Gas | CO₂ | Kilograms | mmBtu | 53.06000 | | Natural Gas | CH₄ | Grams | mmBtu | 1.00000 | | Natural Gas | N₂O | Grams | mmBtu | 0.10000 | | Natural Gas | CO₂ | Kilograms | scf | 0.05444 | | Natural Gas | CH₄ | Grams | scf | 0.00103 | | Natural Gas | N₂O | Grams | scf | 0.00010 | | Petroleum Products | | | | | | Kerosene | CO₂ | Kilograms | mmBtu | 75.20000 | | Kerosene | CH₄ | Grams | mmBtu | 3.00000 | | Kerosene | N₂O | Grams | mmBtu | 0.60000 | | Kerosene-Type Jet Fuel | CO₂ | Kilograms | mmBtu | 72.22000 | | Kerosene-Type Jet Fuel | CH₄ | Grams | mmBtu | 3.00000 | | Kerosene-Type Jet Fuel | N₂O | Grams | mmBtu | 0.60000 | | Propane | CO₂ | Kilograms | mmBtu | 62.87000 | | Propane | CH₄ | Grams | mmBtu | 3.00000 | | Propane | N₂O | Grams | mmBtu | 0.60000 | |
| Table A.3: Solid waste emission factors. 2021 EPA GHG Emission Factor Hub, EPA WARM version 15, November 2020.   | Material | Metric tons CO₂e per short ton material | | --- | --- | | Recycled | | | Mixed Recyclables | 0.09 | | Mixed Organics | NA | | Mixed MSW | NA | | Landfilled | | | Mixed Recyclables | 0.68 | | Mixed Organics | 0.48 | | Mixed MSW | 0.52 | | Combusted | | | Mixed Recyclables | 0.11 | | Mixed Organics | 0.05 | | Mixed MSW | 0.43 | | Composted | | | Mixed Recyclables | NA | | Mixed Organics | 0.17 | | Mixed MSW | NA | |

## A.2 Global Warming Potential (GWP)

The Global Warming Potential (GWP) was developed to allow comparisons of the global warming impacts of different gases. Specifically, it is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO2). The larger the GWP, the more that a given gas warms the Earth compared to CO2 over that time period (USEPA 2023d).

Across all sectors, we used the GWP values established in the Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report (AR6), Table 7.SM.7 (IPCC 2023). We processed these values in [global\_warming\_potential.R](file:///Users/rotenle/R/global_warming_potential.R).

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| Table A.4: Global Warming Potential (GWP) values   | Gas | 100-year GWP value | Source | | --- | --- | --- | | CO₂ | 1.0 | IPCC AR6 (2021) | | CH₄ | 27.9 | IPCC AR6 (2021) | | N₂O | 273.0 | IPCC AR6 (2021) | | CF₄ | 7380.0 | IPCC AR6 (2021) | | HFC-152a1 | 164.0 | IPCC AR6 (2021) | | 1 Hydrofluorocarbon-152a, Difluoroethane | | | |

## A.3 Geographic data

Geographic data were processed in [cprg\_geography.R](file:///Users/rotenle/R/cprg_geography.R).

### A.3.1 Counties

County data was pulled using {tigris}, an R package that downloads TIGER/Line shapefiles from the US Census Bureau (Walker 2023). 2021 geographies for Minnesota and Wisconsin were pulled, combined, and saved.

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| Table A.5: County geography metadata   | Column | Class | Description | | --- | --- | --- | | geoid | character | Five digit county GEOID | | county\_name | character | County name | | county\_name\_full | character | Full county name | | state\_name | character | Full state name | | statefp | character | State FIPS code | | state\_abb | character | Abbreviated state name | | cprg\_area | logical | Whether county is included in the CPRG area | | geometry | sfc\_MULTIPOLYGON | Simple feature geometry | |

Additionally, population estimates were obtained from the American Community Survey 5-Year estimates (2017-2021) using {tidycensus} (U.S. Census Bureau 2021).

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| Table A.6: County population metadata   | Column | Class | Description | | --- | --- | --- | | geoid | character | Five digit county GEOID | | county\_name | character | County name | | state\_name | character | Full state name | | state\_abb | character | Abbreviated state name | | population | numeric | Total county population estimate (persons) | | population\_data\_source | character | Population estimate data source | |

### A.3.2 Cities

Minnesota cities, townships, and unorganized territories were imported from [Minnesota Geospatial Commons](https://gisdata.mn.gov/dataset/bdry-mn-city-township-unorg) (MnDOT 2023b).

Wisconsin cities, towns, and villages were imported from Wisconsin’s Legislative Technology Services Bureau (Wisconsin Legislature 2023).

Data from both states was then combined and filtered to include only the workplan area counties.

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| Table A.7: City geography metadata   | Column | Class | Description | | --- | --- | --- | | ctu\_name | character | City, township, unorganized territory, or village name | | ctu\_class | character | City class (City, township, unorganized territory, or village) | | gnis | character | Minnesota geographic identifier | | geoid\_wis | character | Wisconsin geographic identifier | | geometry | sfc\_MULTIPOLYGON | Simple feature geometry | | thrive\_designation | character | Community designation in Thrive 2040 | | imagine\_designation | character | Community designation in Imagine 2050 | | county\_name | character | County name | | state\_name | character | Full state name | | statefp | character | State FIPS code | | state\_abb | character | Abbreviated state name | | cprg\_area | logical | Whether county is included in the CPRG area | | geometry | sfc\_MULTIPOLYGON | Simple feature geometry | |

# Appendix B — Supplementary tables

## B.1 Acronyms

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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| Table B.1: Acronyms   | Acronym | Definition | | --- | --- | | CAA | Clean Air Act | | CFR | Code of Federal Regulations | | CCAP | Comprehensive Climate Action Plan | | CPRG | Climate Pollution Reduction Grant | | EPA | U.S. Environmental Protection Agency | | GHG | Greenhouse Gas | | GHGRP | Greenhouse Gas Reporting Program (40 CFR Part 98) | | ICR | Information Collection Request | | METC | Metropolitan Council of the Twin Cities | | NEI | EPA’s National Emissions Inventory | | OAR | EPA Office of Air and Radiation | | PCAP | Priority Climate Action Plan | | PM | Project Manager | | PO | EPA Project Officer for Grant | | POP | Period of Performance | | POR | EPA Project Officer’s Representative | | PWP | Project Work Plan | | QA | Quality Assurance | | QAM | Quality Assurance Manager | | QAMD | Quality Assurance Manager Delegate | | QAPP | Quality Assurance Project Plan | | QC | Quality Control | | QCC | Quality Control Coordinator | | LGGIT | Community - GHG Inventory Tool (provided by the EPA) | | TL | Task Leader | | Btu | British thermal unit | | Ccf | volume of 100 cubic feet (cf) | | Mcf | volume of 1,000 cubic feet (cf) | | MMBtu | 1 million British thermal units | | Therm | One therm equals 100,000 Btu, or 0.10 MMBtu | |

## B.2 Data Quality

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| Table B.2: Data source quality ranking   | Quality Rank | Source Type | | --- | --- | | Highest | Federal, state, and local government agencies | | Second | Consultant reports for state and local government agencies | | Third | NGO studies; peer-reviewed journal articles; trade journal articles; conference proceedings | | Fourth | Conference proceedings and other trade literature: non-peer-reviewed | | Fifth | Individual estimates (e.g., via personal communication with vendors) | |

# Appendix C — Additional resources

## Climate Pollution Reduction Grants (CPRG)

* Climate Pollution Reduction Grants [EPA site](https://www.epa.gov/inflation-reduction-act/climate-pollution-reduction-grants) and [SAM.gov](https://sam.gov/fal/6ccff3d73583450ba88ecef4bee21212/view)
* Funding information for this project on [USASpending.gov](https://www.usaspending.gov/award/ASST_NON_00E03476_6800)

## Energy

* U.S. Energy Information Administration (EIA) Glossary, available on their [website](https://www.eia.gov/tools/glossary/).

## Minnesota statewide efforts

* [Transportation Greenhouse Gas Emissions Impact Assessment Technical Advisory Committee](https://www.dot.state.mn.us/sustainability/ghg-tac.html)
* [Other MnDOT committees, councils, and working groups](https://www.dot.state.mn.us/sustainability/committees.html)
* Minnesota statewide Priority Climate Action Plan (PCAP) [engagement page](https://engage.eqb.state.mn.us/climate-priorities)
* [Minnesota Climate Action Framework (CAF)](https://climate.state.mn.us/minnesotas-climate-action-framework)

# Appendix D — Utility service area maps

To identify the utilities operating within our 11-county study area, we utilized data sets published by state and federal sources. The outcome of our data collection yields a list of distinct utilities suplying activity data and resides within [distinct\_natGas\_util\_WI.RDS](file:///Users/rotenle/Downloads/data/distinct_natGas_util_WI.RDS) (4 utilities, all investor-owned) and [distinct\_natGas\_util\_type\_MN.RDS](file:///Users/rotenle/Downloads/data/distinct_natGas_util_type_MN.RDS) (7 utilities, six investor-owned and one municipally-owned).

### D.0.1 Minnesota

Since there is no state-maintained map of natural gas service territories in Minnesota (Minnesota IT Services 2021), we looked to the Homeland Infrastructure Foundation-Level Data (HIFLD) database, a product of the Department of Homeland Security’s Geospatial Management Office (DHS GMO) that compiles “foundation-level geospatial data” for homeland security, homeland defense, and emergency preparedness purposes. This dataset was last updated in 2017 (Homeland Security 2017). Though this dataset is national in scope (see [Figure D.1](#fig-minnesota-ng-servTerrs)), it is clipped to only include utility service areas within the nine Minnesota counties included in the study area of this inventory (see [Figure D.2](#fig-MN-ng-inScope-servTerrs)). Note that utilities operating across county lines have a polygon covering the extent of their service territory within each and every county they operate within.

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| Figure D.1: Nationwide utility service service territories |
| Figure D.2: Minnesota utility service service territories in scope |

### D.0.2 Wisconsin

The Public Service Commission of Wisconsin publishes and maintains maps of service territories for natural gas utilities operating within the state. This data set relies upon, and is accurate to, “the extent that various sources [utilities] supplied accurate data.” (Public Service Commission of Wisconsin 2021). This dataset spans the whole state of Wisconsin (see [Figure D.3](#fig-wisconsin-ng-servTerrs)), but was clipped to the two Wisconsin counties included in the study area of this inventory (see [Figure D.4](#fig-wisconsin-ng-inScope-servTerrs)).

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| Figure D.3: Wisconsin utility service service territories |

Wisconsin utilities in scope

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| Figure D.4: Wisconsin utility service service territories in scope |

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# Appendix G — Release notes

## v2.0.0 (February 2025)

This release incorporates major changes to all sectors, including temporal data back to 2005 and fundamental changes in methodology. We also now account for industrial and agricultural emissions.

* Energy
  + Electricity and natural gas data have utility report data for 2005 and 2013-2021
  + Electricity and natural gas data are split into residential, commercial, and industrial per NREL modeling for all years
  + Electricity and natural gas are now categories in the sectors residential, commercial, and industrial
* Transportation
  + Transportation emissions are calculated using a different method; in previous versions, we used a 100/50/50 origin-destination method. Now we are using a VMT-based method.
  + **Emissions estimates from previous releases should not be directly compared with this and all future releases.**
  + Transportation emissions are compiled from EPA data sources, including the National Emissions Inventory (NEI), EPA EQUATES, and the Air Emissions Modeling Platform.
  + Bus, passenger, and commercial modes are accounted for.
  + Preliminary aviation emissions accounted for.
* Waste
  + Solid waste now follows IPCC guidelines instead of previous simplistic activity-EF model
  + Solid waste emissions are apportioned to CTU by population
  + Wastewater is now calculated based off county and CTU population, instead of apportioned from state totals
* Industrial
  + New sector, partially informed by previous energy work
  + New emissions data from state and federal point source data includes process emissions and additional fuel combustion
* Agriculture
  + New sector detailing emissions from livestock and crop production
  + Data sources are USDA county agriculture censuses and EPA emission factors
* Natural Systems
  + Sequestration now relies entirely on USGS NLCD model (WorldCover data removed for now)
  + Adds freshwater emissions data following National Hydrography Database and state emission factors
* Other data
  + County and CTU population data back to 2005.

See full changelog in GitHub release [v2.0.0](https://github.com/Metropolitan-Council/ghg-cprg/releases/tag/v2.0.0)

## v1.1.1 (July 2024)

Minor changes across all sectors (excluding natural systems) by updating GWP values to AR6 (IPCC 2023).

Additional changes

* Some energy data processing to get back to 2005 in \_energy/data-raw/MNWI\_2005\_CensusCrosswalk\_UtilityAllocation.R
* Text for GWP updated [Section A.2](#sec-gwp)
* Noted differences in LGGIT values **?@sec-epa-lggit-transportation**
* Re-ran transportation LGGIT comparison values. Minor change in values
* Test values updated for EPA MOVES and GWP
* Slight updates to renv package repository locations (RSPM vs. CRAN)
* Minor text update in transportation section
* Zotero and gitignore updated as needed

See full changelog in GitHub release [v1.1.1](https://github.com/Metropolitan-Council/ghg-cprg/releases/tag/v1.1.1)

## v1.1.0 (June 2024)

NEW SECTOR - Natural systems sequestration and carbon stock ([Chapter 22](#sec-natural-systems)).

Natural systems sequestration and carbon stock at county level, with particular focus on regional parks. Data sources include WorldCover and USGS NLCD. Sequestration rates and carbon stock potential come from various literature as cited. Values are correlated with county area in square kilometers.

Additional changes

* Increment release version to 1.1.0, increment date
* Updates R version to 4.4.0 and Quarto version to 1.4.533
* Update renv packages to follow R 4.4.0
* New packages FedData, terra, tidyterra, usethis, arcgislayers, dbplyr, and various sub-dependencies
* Start changelog section in appendix
* Start folder structure for agriculture sector
* Various text edits and updates, including references

See full changelog in GitHub release [v1.1.0](https://github.com/Metropolitan-Council/ghg-cprg/releases/tag/v1.1.0)

## v1.0.0 (March 2024)

Initial release supporting [PCAP](https://www.metrocouncil.org/tcghginventory). Sections include

* Stationary energy (electricity, natural gas, propane and kerosene)
* Transportation (passenger, commercial)
* Waste and wastewater (solid waste, wastewater)
* Appendices with utility service area maps, low-income and disadvantaged communities (LIDAC)

See full changelog in GitHub release [v1.0.0](https://github.com/Metropolitan-Council/ghg-cprg/releases/tag/v1.0.0)

# References

“2006 IPCC Guidelines for National Greenhouse Gas Inventories.” 2006. Intergovernmental Panel on Climate Change. <https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol5.html>.

Administration, U. S. Energy Information. 2023. “How Much Electricity Is Lost in Electricity Transmission and Distribution in the United States?” Frequently Asked Questions. 2023. <https://www.eia.gov/tools/faqs/faq.php?id=105>.

Beidler, James, and Alison Eyth. 2024. “Blank Emis\_type.” CMAS Center Forum. October 9, 2024. <https://forum.cmascenter.org/t/blank-emis-type/5244/7>.

CMAS. 2024. “SMOKE V5.1 User’s Manual.” Chapel Hill: Community Modeling and Analysis System Center (CMAS). <https://www.cmascenter.org/smoke/documentation/5.1/html/ch02s02s03.html>.

Commerce, Minnesota Department of. 2005. *CHAPTER 7610, ENERGY INFORMATION REPORTING*. <https://www.revisor.mn.gov/rules/7610/>.

Elk River Municipal Utilities. 2022. “2021 Annual Financial Report.” Financial report. <https://www.ermumn.com/application/files/3316/5668/9846/2021_Annual_Financial_Report.pdf>.

Energy, Xcel. n.d. “Xcel Energy Community Energy Reports.” Xcel Energy. <https://www.xcelenergy.com/community_energy_reports>.

Foley, Kristen M., George A. Pouliot, Alison Eyth, Michael F. Aldridge, Christine Allen, K. Wyat Appel, Jesse O. Bash, et al. 2023. “2002–2017 Anthropogenic Emissions Data for Air Quality Modeling over the United States.” *Data in Brief* 47 (April): 109022. <https://doi.org/10.1016/j.dib.2023.109022>.

Foley, Kristen, Allison Eyth, and Christopher Allen. 2024. “Nitrous Oxide (N2O) Availability in EQUATES County-Level.” CMAS Center Forum. September 24, 2024. <https://forum.cmascenter.org/t/nitrous-oxide-n2o-availability-in-equates-county-level/5199/5>.

Fong, Wee Kean, Mary Sotos, Michael Doust, Seth Schultz, Ana Marques, and Chang Deng-Beck. 2021. “Global Protocol for Community-Scale Greenhouse Gas Inventories.” Version 1.1. World Resources Institute, C40 Cities Climate Leadership Group, and ICLEI - Local Governments for Sustainability. <https://ghgprotocol.org/ghg-protocol-cities>.

Holt, Dominic. 2019. “Wisconsin’s Clean Energy Policies.” Government. Wisconsin Department of Natural Resources. <https://dnr.wisconsin.gov/sites/default/files/topic/ClimateChange/WisconsinCleanEnergyPolicies.pdf>.

Homeland Security, Department of. 2017. “Natural Gas Service Territories - Homeland Infrastructure Foundation-Level Data.” <https://hifld-geoplatform.opendata.arcgis.com/maps/natural-gas-service-territories>.

IPCC. 2023. *Climate Change 2021 – The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. 1st ed. Cambridge University Press. <https://doi.org/10.1017/9781009157896>.

Ma, Ookie, Ricardo P Cardoso De Oliveira, Evan Rosenlieb, and Megan H Day. 2019. “Sector-Specific Methodologies for Subnatonal Energy Modeling.” NREL/TP-7A40-72748, 1506626. <https://doi.org/10.2172/1506626>.

Minnesota Department of Commerce. 2022. “Annual Reporting Forms for Electric and Gas Utilities.” Government/regulatory filings. Annual Reporting. 2022. <https://mn.gov/commerce/energy/industry-government/utilities/annual-reporting.jsp>.

Minnesota IT Services. 2021. “Public Utilities Infrastructure Information for Minnesota.” 2021. <https://www.mngeo.state.mn.us/chouse/utilities.html>.

MnDOT. 2023a. “TFA Data Collection Methods.” Government. 2023. <https://www.dot.state.mn.us/traffic/data/coll-methods.html#TVPO>.

———. 2023b. “City, Township, and Unorganized Territory in Minnesota - Minnesota Geospatial Commons.” Minnesota Geospatial Commons. <https://gisdata.mn.gov/dataset/bdry-mn-city-township-unorg>.

MPCA. 2023. “Climate Change Trends and Data.” 2023. <https://www.pca.state.mn.us/air-water-land-climate/climate-change-trends-and-data>.

New Prague Utilities Commission. 2022. “Agenda & Packet, 1/24/2022 Meeting of the New Prague Utilities Commission (Incl. Financial Report).” Utility. <https://www.ci.new-prague.mn.us/vertical/sites/%7BAD7ECB62-2C5E-4BA0-8F19-1426026AFA3E%7D/uploads/01-24-2022_Utilities_Commission_Meeting_Packet.pdf>.

NREL. 2017. “SLOPE: State and Local Planning for Energy.” <https://maps.nrel.gov/slope/>.

Office, Minnesota IT Geospatial Information. 2023. “Electric Utility Service Areas, Minnesota, January 2023.” <https://gisdata.mn.gov/dataset/util-eusa>.

Public Service Commission of Wisconsin. 2021. “PSC Interactive Service Area Maps.” <https://psc.wi.gov/Pages/ForConsumers/Maps.aspx>.

———. 2022. “Annual Reports : View PDFs, Queries, and Programs.” Government/regulatory filings. Annual Reporting. 2022. <https://apps.psc.wi.gov/ARS/annualReports/default.aspx>.

U.S. Census Bureau. 2021. “ACS Demographic and Housing Estimates.” U.S. Census Bureau. <https://data.census.gov/table/ACSDP5Y2021.DP05?g=050XX00US27053_040XX00US27>.

U.S. Energy Information Administration. 2023. “Annual Electric Power Industry Report, Form EIA-861 Detailed Data Files (2021).” <https://www.eia.gov/electricity/data/eia861/>.

US EIA. 2023. “2020 Residential Energy Consumption Survey: Consumption and Expenditures Technical Documentation Summary.” Government. Washington, DC 20585: U.S. Department of Energy. <https://www.eia.gov/consumption/residential/data/2020/pdf/2020%20RECS%20CE%20Methodology_Final.pdf>.

USEPA. 2015. “2011 National Emissions Inventory, Version 2 Technical Support Document.” Government. <https://www.epa.gov/sites/default/files/2015-10/documents/nei2011v2_tsd_14aug2015.pdf>.

———. 2018. “2014 National Emissions Inventory, Version 2 Technical Support Document.” Government. <https://www.epa.gov/sites/default/files/2018-07/documents/nei2014v2_tsd_05jul2018.pdf>.

———. 2019. “WARM - Management Practices Chapters (Version 15).” Government. US EPA Office of Resource Conservation and Recovery, Prepared by ICF. <https://www.epa.gov/sites/default/files/2019-10/documents/warm_v15_management_practices_updated_10-08-2019.pdf>.

USEPA. 2021a. “eGRID (Emissions & Generation Resource Integrated Database) 2021 Summary Data.” <https://www.epa.gov/egrid/summary-data>.

———. 2021b. “Emissions Factors for Greenhouse Gas Inventories.” <https://www.epa.gov/system/files/documents/2023-04/emission-factors_sept2021.pdf>.

USEPA. 2021c. “2017 National Emissions Inventory: January 2021 Updated Release, Technical Support Document.” Government EPA-454/R-21-001. <https://www.epa.gov/sites/default/files/2021-02/documents/nei2017_tsd_full_jan2021.pdf>.

———. 2023a. “2020 National Emissions Inventory Technical Support Document: Onroad Mobile Sources.” Government EPA-454/R-23-001e. Office of Air Quality Planning and Standards. <https://www.epa.gov/air-emissions-inventories/2020-national-emissions-inventory-nei-technical-support-document-tsd>.

———. 2023b. “Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021.” Reports and Assessments. <https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2021>.

———. 2023c. “2020 National Emissions Inventory Technical Support Document: Introduction.” Government EPA-454/R-23-001a. Office of Air Quality Planning; Standards. <https://www.epa.gov/air-emissions-inventories/2020-national-emissions-inventory-nei-technical-support-document-tsd>.

———. 2023d. “Understanding Global Warming Potentials.” Government. April 18, 2023. <https://www.epa.gov/ghgemissions/understanding-global-warming-potentials>.

———. 2024a. “State Greenhouse Gas Inventory and Projection Tools.” Government. <https://www.epa.gov/statelocalenergy/download-state-inventory-and-projection-tool>.

———. 2024b. “2021 Emissions Modeling Platform.” Air Emissions Modeling Platforms. February 6, 2024. <https://www.epa.gov/air-emissions-modeling/2021-emissions-modeling-platform>.

———. 2024c. “2022v1 Emissions Modeling Platform.” Air Emissions Modeling Platforms. August 23, 2024. <https://www.epa.gov/air-emissions-modeling/2022v1-emissions-modeling-platform>.

USEPA, Janice Godfrey, and Alison Eyth. 2022. “Development of 2020 Default Onroad Activity Data for the National Emissions Inventory.” <https://gaftp.epa.gov/air/nei/2020/doc/supporting_data/onroad/DefaultOnroadActivity.pdf>.

Walker, Kyle. 2023. *Tigris: Load Census TIGER/Line Shapefiles*. Manual. <https://CRAN.R-project.org/package=tigris>.

Wisconsin DNR. 2021. “Wisconsin Greenhouse Gas Emissions Inventory Report.” Government AM-610-2021. Madison, Wisconsin. <https://widnr.widen.net/view/pdf/o9xmpot5x7/AM610.pdf?t.download=true>.

Wisconsin Legislature. 2023. “Wisconsin Cities, Towns and Villages (July 2023).” Legislative Technology Services Bureau (LTSB). <https://gis-ltsb.hub.arcgis.com/datasets/LTSB::wi-cities-towns-and-villages-july-2023/explore>.

Wisconsin Public Service Commission, Division of Energy Regulation, and Tyler Tomaszewski. 2024. “Electric Service Territories.” <https://maps.psc.wi.gov/portal/apps/webappviewer/index.html?id=bb1a9f501e3d472cbde970310540b466>.

Wisconsin State Legislature. 2024. *Chapter 196, Regulation of Public Utilities*. *35.18*. <https://docs.legis.wisconsin.gov/statutes/statutes/196>.

WisDOT. 2023. “Transportation Planning Manual - Chapter 9 Traffic Forecasting, Travel Demand Models and Planning Data.” Government. Bureau of Planning and Economic Development, Traffic Forecasting Section. <https://wisconsindot.gov/Documents/projects/data-plan/plan-res/tpm/9.pdf>.

1. All six MOVES emissions processes, including rate per distance (RPD), rate per vehicle (RPV), rate per hour (RPH), rate per profile (RPP), rate per start (RPS), and rate per hour for off-network idling (RPHO) were summed for each vehicle type, fuel type, and pollutant (Beidler and Eyth 2024) [↑](#footnote-ref-1)