Evaluating Carbon Emissions from Electric Arc Furnace Steel Plants in the United States

Technical Documentation

UNIVERSITY OF CALIFORNIA
Santa Barbara

Evaluating Carbon Emissions from Electric Arc Furnace Steel Plants in the United States

A Capstone Project submitted in partial satisfaction of the requirements for the degree of Master of Environmental Data Science for the Bren School of Environmental Science & Management

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Signature Page

EVALUATING ELECTRIC ARC FURNACE STEEL PLANT EMISSIONS IN THE UNITED STATES

As developers of this Capstone Project documentation, we archive this documentation on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.

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The Capstone Project is required of all students in the Master of Environmental Data Science (MEDS) Program. The project is a six-month-long activity in which small groups of students contribute to data science practices, products or analyses that address a challenge or need related to a specific environmental issue. This MEDS Capstone Project Technical Documentation is authored by MEDS students and has been reviewed and approved by:

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Roland Geyer

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Ruth Oliver

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Date

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Abstract

Iron and steel production accounts for 11% of global carbon emissions.[1] Most steel in the world is produced with a combination of blast furnaces and basic oxygen furnaces (BF-BOF), which burn coal and have a relatively high carbon emissions intensity. However, in the United States, around 70% of steel is produced with electric arc furnaces (EAF).[2] This process uses electricity, rather than burning coke, to melt scrap and other inputs. Therefore, the direct, Scope 1, emissions of EAF-produced steel are lower than BF-BOF produced steel, but there are still indirect, or Scope 2, carbon emissions associated with the required electricity inputs. As the US steel industry seeks to decarbonize and promote green steel, understanding the Scope 2 emissions of EAF steel production is essential. While Scope 1 emissions data is publicly available, there's currently no transparency or accountability for the Scope 2 emissions associated with EAF steel plants. This project calculates the Scope 2 emissions and the emissions intensity of the electric steel plants in the United States and combines those calculations Scope 1 emissions data to prove a comprehensive analysis of the carbon footprint of each EAF steel plant in the US for Global Energy Monitor, an organization dedicated to open, accessible data to create transparency in the energy industry.

[1] Hasanbeigi, Ali. "Steel Climate Impact." Global Efficiency Intelligence, 2022. https://www.globalefficiencyintel.com/steel-climate-impact-international-benchmarking-energy-co2-intensities.

[2] American Iron and Steel Institute. "Steel Production," 2023. https://www.steel.org/steel-technology/steel-production/.

Executive Summary

Globally, iron and steel production account for 11% of carbon dioxide emissions.[3] Electrified steel production using Electric Arc Furnace (EAF) technology is a promising path for decarbonization in this sector. In the US, around 70% of steel is produced with EAF technology, which uses electricity to create steel from scrap and other inputs.[4] In contrast, steel produced in the rest of the world comes primarily from blast furnaces and basic oxygen furnaces. This method requires burning coal at the plant to produce steel from iron ore inputs. This results in much greater direct (Scope 1) and indirect (Scope 2) carbon dioxide equivalent (CO_2e) emissions compared to EAF steel production. In comparison, EAF steel production has lower overall emissions, but the Scope 2 emissions are typically greater than the Scope 1 emissions. Currently, only Scope 1 emissions are publicly available at the plant-level for EAF steel plants in the US. The steel industry is facing pressure to decarbonize,[5] but there is a lack of transparency and no public information about the emissions intensity of EAF steel production at the individual plant level.

Global Energy Monitor (GEM), our client, wants to fill this knowledge gap by estimating the emissions intensity of EAF steel production at the plant level in the US. Our team, SteelTracker, achieved this using public data from GEM's Global Steel Plant Tracker (GPST) on steel plant capacity, ownership, and location[6], American Iron and Steel Institute (AISI) data on regional steel production compiled by our client, and electric grid emissions intensity data downloaded from the EPA's eGrid tool.[7] These datasets allowed us to calculate the Scope 2 emissions and emissions intensity of each steel plant per unit of steel production on weekly and annual time scales. To achieve this, several key assumptions were made: all EAF plants were assumed to draw 100% of their electricity from the grid, and a uniform energy intensity value for steel production was used assuming 100% steel scrap inputs. Additional assumptions are documented in Appendix C.

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[3] Hasanbeigi, A. 2022. Steel Climate Impact. https://www.globalefficiencyintel.com/steel-climate-impact-international-benchmarking-energy-co2-intensities.

[4] World Steel Association. "World Steel in Figures 2022," n.d. https://worldsteel.org/steel-topics/statistics/world-steel-in-figures-2022/#major-steel-producing-countries-2021-and-2020.

[5] Hasanbeigi, Ali, and Adam Sibal. "What Is Green Steel? Definitions and Scopes from Standards, Protocols, Initiatives, and Policies around the World." Global Efficiency Intelligence, 2023. https://www.globalefficiencyintel.com/what-is-green-steel.

[6] "Global Steel Plant Tracker." Global Energy Monitor, March 31, 2023. https://globalenergymonitor.org/projects/global-steel-plant-tracker/.

[7] EPA. Emissions & Generation Resource Integrated Database (eGRID). https://www.epa.gov/egrid.

Our analysis revealed that the Scope 2 emissions at each EAF plant were greater than the reported Scope 1 emissions, and thus a significant portion of the carbon footprint that is not publicly or uniformly accounted for. The standardized dataset created contributes to GEMs ongoing efforts to trace emissions from steel production and call for transparency and accountability within the industry. Additionally, the reproducible workflow from this project can be reused when future years of data are published by the EPA and AISI. This allows GEM to continue to track Scope 2 emissions at each plant for years to come.

In addition to the dataset and workflow, SteelTracker also created an interactive Tableau dashboard to show the emissions intensity of steel plants across the country. Tableau makes it easy for our users to explore the data without coding or doing any data analysis themselves. The filtering features also make it easy for GEM and its users to quickly compare the emissions intensities across different EAF steel plants. This is the first publicly available information on the Scope 2 emissions for EAF plants in the US. Our results provide clear, traceable information that analysts, industry groups, policymakers, advocacy groups, and steel industry professionals can use to inform decision-making around decarbonization.

Problem Statement

Currently, only Scope 1 emissions are reported at the facility level for steel plants in the US. However, the Scope 2 emissions from electric steel production at EAF plants are a significant portion of the carbon footprint of steel production. This creates a carbon accounting gap in the publicly available data on electric steel production.

Electrified steel production using EAF technology is a promising path for decarbonization in this sector. The US in particular is positioning itself as a leader in clean steel and green steel production.[8] Leading steel companies tout their EAF technology and scrap inputs as a way to more sustainably create steel.[9] However, because the Scope 2 emissions associated with electrified steel production are significant, there's a need for public, open data to back up these claims of green steel.

Global Energy Monitor (GEM), our client, is committed to developing and sharing information relevant to the global clean energy transition. GEM currently maintains a comprehensive dataset on worldwide steel production in its Global Steel Plant Tracker.[10] Estimates and company self-reported Scope 1 emissions are available at varying levels of granularity. While data about US energy emissions exist, and steel plant energy consumption exists, there is no publicly available source of data that provides insight into how much energy-related (Scope 2) emissions are produced by EAF steel plants in the US. This project meets the client's need to create transparency in the steel industry and create public knowledge of the carbon intensity of EAF steel production. This information is useful for GEM's mission and serves the organizations that rely on GEM's data. GEM provides information to multinational organizations, consulting firms, news agencies, and industry.

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[8] Gamage, Chathurika, Kaitlyn Ramirez, Nick Yavorsky, and Lachlan Wright. "Forging a Clean Steel Economy in the United States." RMI, March 9, 2023. https://rmi.org/forging-a-clean-steel-economy-in-the-united-states.

[9] "Sustainability Report 2021." Cleveland-Cliffs Inc., 2021. https://d1io3yog0oux5.cloudfront.net/_c8bc841bcb126ca3e376a300c5b8abc0/clevelandcliffs/db/1188/11273/file/CLF_Report_Sustainability_2021_SinglePages.pdf.

[10] "Global Steel Plant Tracker." Global Energy Monitor, March 31, 2023. https://globalenergymonitor.org/projects/global-steel-plant-tracker/.

Specific Objectives

Our project aims to calculate and analyze the emissions intensity of electrified steel production in the US. To create transparency on carbon emissions from EAF steel, we set out to:

- Calculate the 2021 *annual* Scope 2 carbon emissions for each EAF steel plant in the US.
- Calculate the 2021 *weekly* Scope 2 carbon emissions for each EAF steel plant in the US.
- Calculate the emissions intensity in metric tons of carbon dioxide equivalent produced per metric ton of steel produced at each plant.
- Combine the calculated Scope 2 emissions with the Scope 1 emissions reported through the EPA's Greenhouse Gas Reporting Program for each plant at weekly and annual time scales for 2021.
- Create an interactive Tableau dashboard for users to view the calculated emissions and emissions intensity values for both annual and weekly time scales.
- Summarize our findings in a written report accompanied by visualizations from our dataset.

Summary of Solution Design

To achieve the objectives outlined above, we acquired publicly available data on EAF steel plant locations, production capacities, utilization rates, Scope 1 emissions, and the carbon emissions intensity of the electricity grid each plant draws from. Our calculations relied on several key assumptions, outlined in detail in Appendix C. The data we joined and used to calculate Scope 2 emissions were imported to Tableau to create an interactive visualization. The key steps in the solution design are outlined below.

1. Data Acquisition

To calculate the Scope 2 carbon emissions at the individual plant level, data from four primary sources was acquired.

- **GEM**, our client, provided data from its Global Steel Plant Tracker on steel plant names, locations, addresses, capacities (in metric tons of steel per annum), product type, and other variables. A complete list of variables is provided in the metadata in Appendix A.

- **American Iron and Steel Institute** (AISI) sends out weekly data on regional steel production rates. Our client has collated these values for each AISI region and provided them to us in a csv file. Steel plants were assumed to have the weekly utilization rate of the region in which they are located.
- **EPA eGRID** data provides the CO_2 equivalent (CO_2e) emissions intensity for each grid subregion at the annual level. Our calculations assume that each EAF steel plant is powered 100% by grid electricity with no on-site generation. While this is not the case for every plant, we believe it is a useful approximation. Our subregions are based off of 2020 shapefiles but the data is updated for 2021.
- **EPA Greenhouse Gas Reporting Program** data, accessed through the Facility-level information on Greenhouse Gas Tool (FLIGHT), provides the reported Scope 1 carbon emissions for each plant.

In addition to the data sources above, the report “Industrial Electrification in U.S. States” by Ali Hasanbeigi, Lynn Kirshbaum, and David Gardiner was also referenced to find the average energy intensity of EAF steel production from scrap.[11] This assumption of 710 kWh/metric ton was crucial in calculating emissions, documented in more detail in Appendix C.

2. Data Joining and Analysis

The relevant variables and observations from the datasets described above were combined by each unique plant. For each dataset, units were standardized to metric tons of steel and metric tons of CO_2e.

EAF plants in the GEM dataset were paired to the energy intensity of the grid they are hooked up to by their locations. Using the eGrid data which provide region names, and the eGrid shapefiles, which provide vector data for those regions, the steel plants were matched to the correct eGrid subregions based on latitude and longitude. The AISI capacity utilization rates were also provided regionally, so steel plants were again matched to the correct regional utilization rate based on state, or in some cases where multiple regions existed in a state, by municipality. The formula below was then used to calculate the CO_2e emissions intensity and weekly emissions (Figure 1).

[11] Hasanbeigi, Ali, Lynn Krishbaum, and David Gardiner. “Industrial Electrification in U.S. States.” Global Efficiency Intelligence, February 2023. https://www.globalefficiencyintel.com/industrial-electrification-in-us-states.

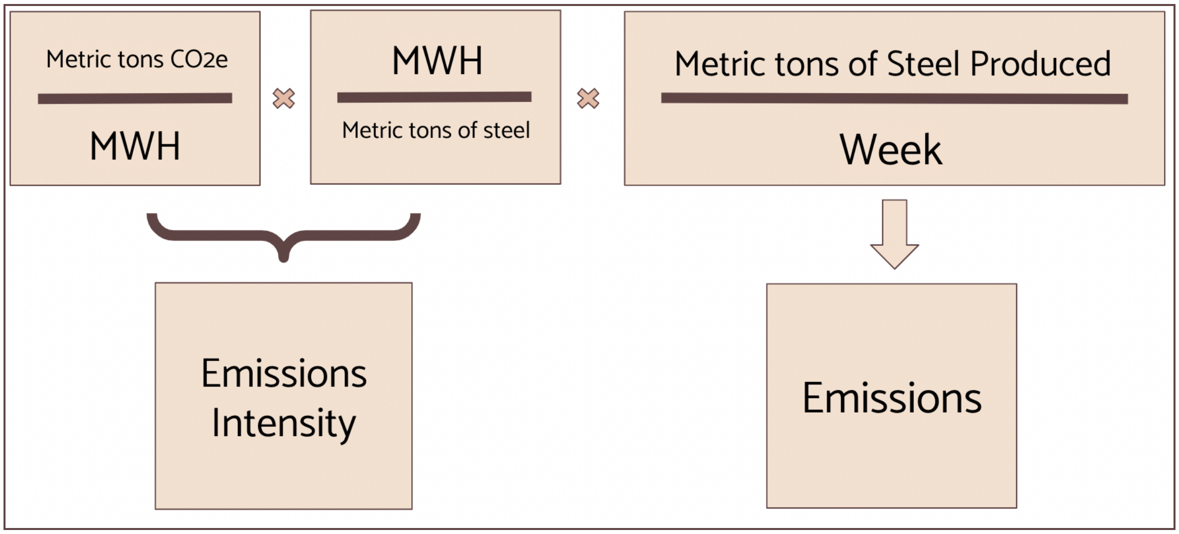

Figure 1: The equation above shows how the weekly Scope 2 emissions were calculated at each EAF plant.

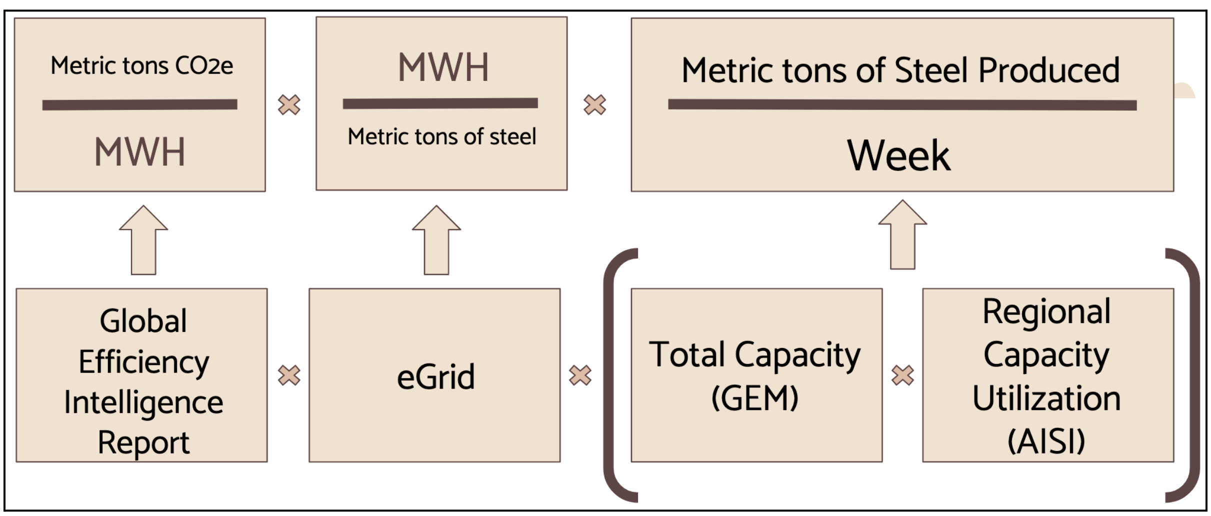

Figure 1.1: The equation above shows the data sources for each portion of the equation we used to calculate scope 2 emissions.

Once Scope 2 values were calculated, the self-reported Scope 1 emissions values from the EPA's FLIGHT tool were matched to each steel plant. Steel plant names, coordinates, and addresses aren't standard between the EPA and GEM datasets, so steel plants were matched on zip code. There were several exceptions where plants couldn't be matched due to non-operational status or errors in the entered data. These exceptions are documented in Appendix B.

This data manipulation was completed in R as the project team's primary language is R. The code was then translated to an analogous Python workflow for the client's convenience.

3. Tableau Visualizations

The dataset we created through the steps above was imported to Tableau Public to create an interactive dashboard to display the Scope 2 CO_2e emissions at each EAF steel plant in the US. The dashboard allows users to see the emissions intensity per metric ton of steel production at each plant, as well as the overall emissions and production capacities. The dashboard is accessible at https://public.tableau.com/app/profile/steel.tracker.

4. Written Summary

The key findings from our calculations, analysis, and visualizations are summarized for our client in a brief report, also available in the GitHub repository as a PDF for public viewing.

Products and Deliverables

The project deliverables comprise:

A standardized dataset that includes the emissions intensity of steel production for each EAF steel plant in the US, and the overall annual and weekly Scope 2 CO_2e emissions for each plant in 2021. Weekly and annual values for the total Scope 1 and Scope 2 combined emissions and emissions intensities are also included. In addition to the CO_2e emissions values calculated, the dataset includes plant-level identification information from GEM's Global Steel Plant Tracker. Details on the variables included in the data are available in Appendix A.

This data is available for download in CSV format by contacting our client, caitlin.swalec@globalenergymonitor.org. Although this data is publicly available, keeping access monitored through GEM supports our client's aim to understand who is using their data.

Calculations and analysis that were run to determine the plant-level Scope 2 emissions. This analysis is available in an R markdown document, written in R, and a Jupyter notebook, written in Python, so that users can reuse the analysis in their language of preference. This analysis allows GEM to obtain the same Scope 2 calculations for future years once new data gets published by the EPA and AISI.

A Tableau dashboard displaying the locations of each EAF steel plant and their associated Scope 2 and Scope 1 emissions. Users can filter between views to see the annual 2021 Scope 2 emissions for 2021, the weekly Scope 2 emissions in 2021, and the combined annual Scope 1 and two emissions for each plant where 2021 Scope 1 emissions data was available. You can view and explore the dashboard at https://public.tableau.com/app/profile/steel.tracker. Screenshots of the main dashboard pages are shown below (Figures 2 - 7).

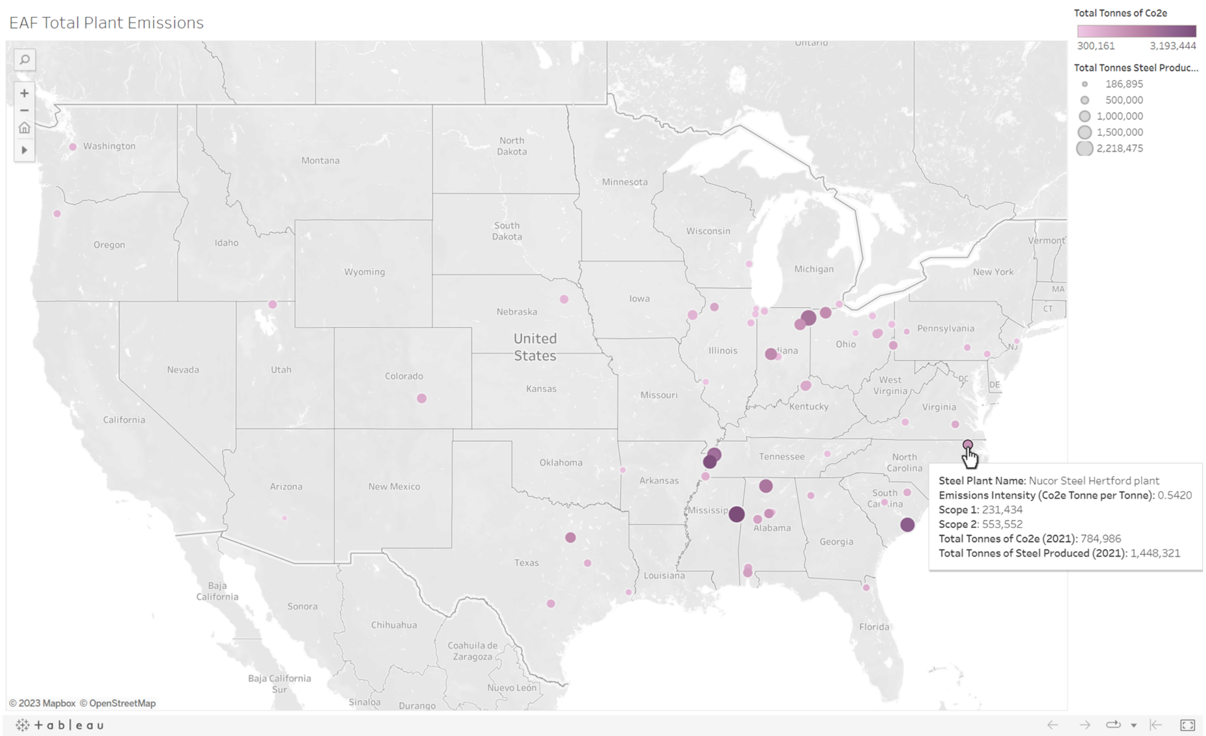

Figure 2: This map displays the total Scope 1 and Scope 2 combined plant emissions for 2021. The size of the circle indicates production amounts for each plant, and the darker shades of purple indicate higher emissions amounts.

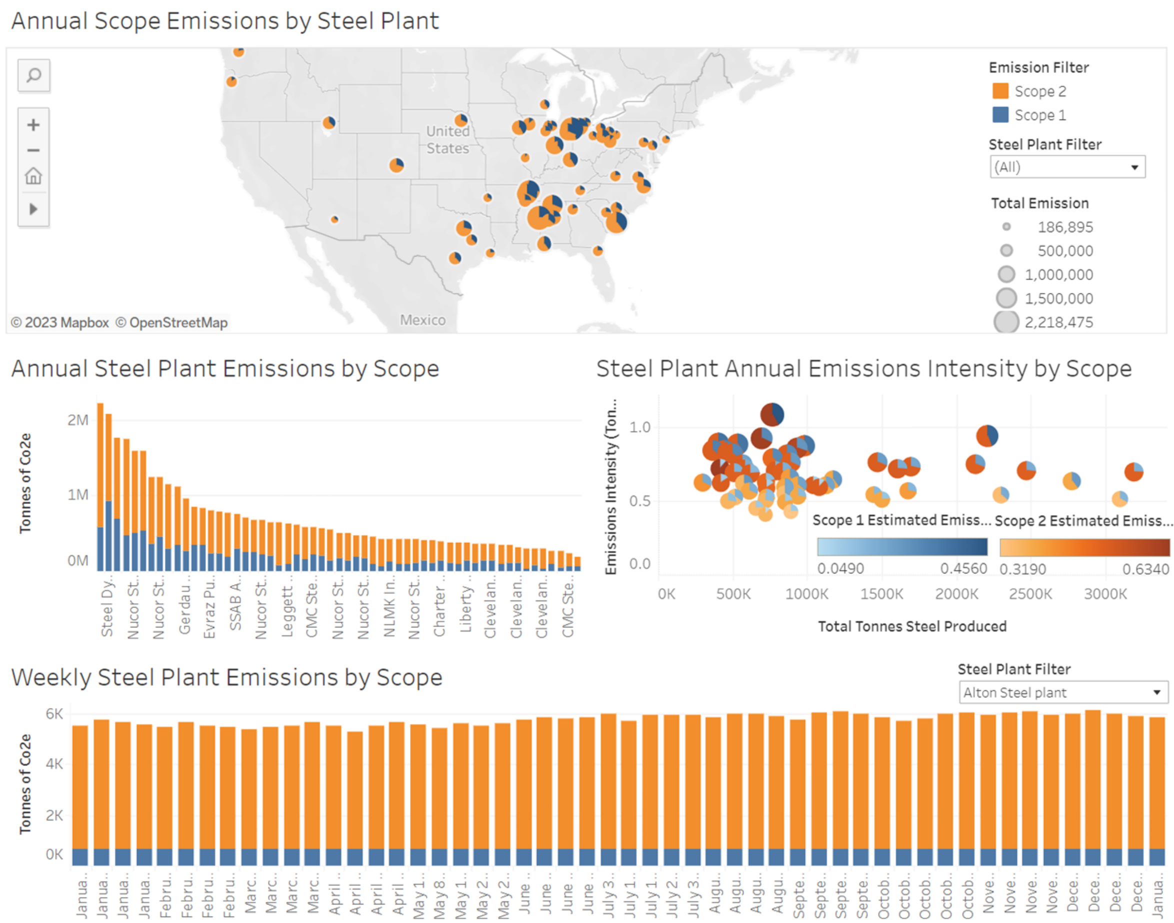

Figure 3.1 2021 North America Steel Tracker - Interactive Tableau Dashboard showing Annual Scope Emissions by Steel Plant, Annual Steel Plant Emissions by Scope, Steel Plant Annual Emissions Intensity by Scope, and Weekly Steel Plant Emissions by Scope.

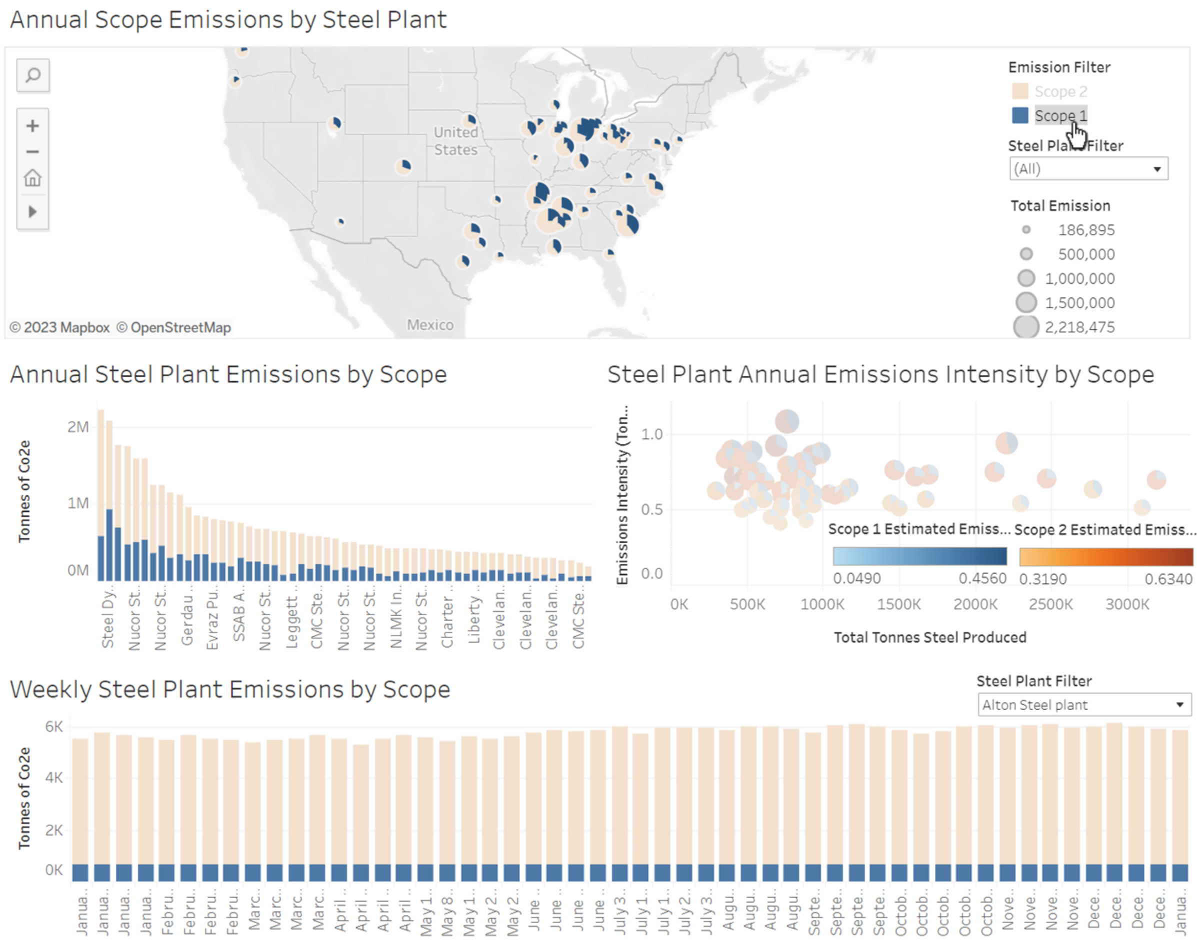

Figure 3.2 2021 North America Steel Tracker - Interactive Tableau Dashboard highlighting Scope 1 emissions.

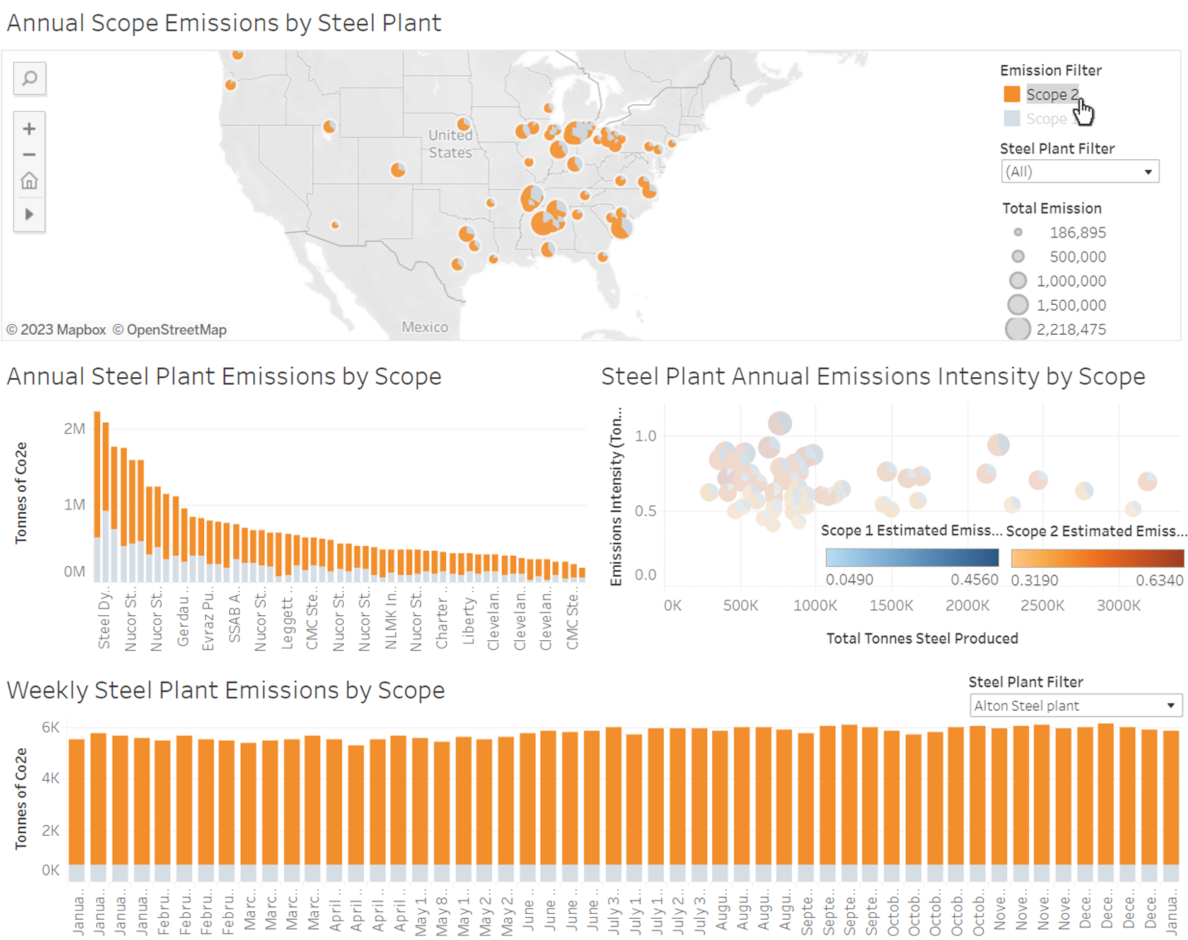

Figure 3.3 2021 North America Steel Tracker - Interactive Tableau Dashboard highlighting Scope 2 emissions.

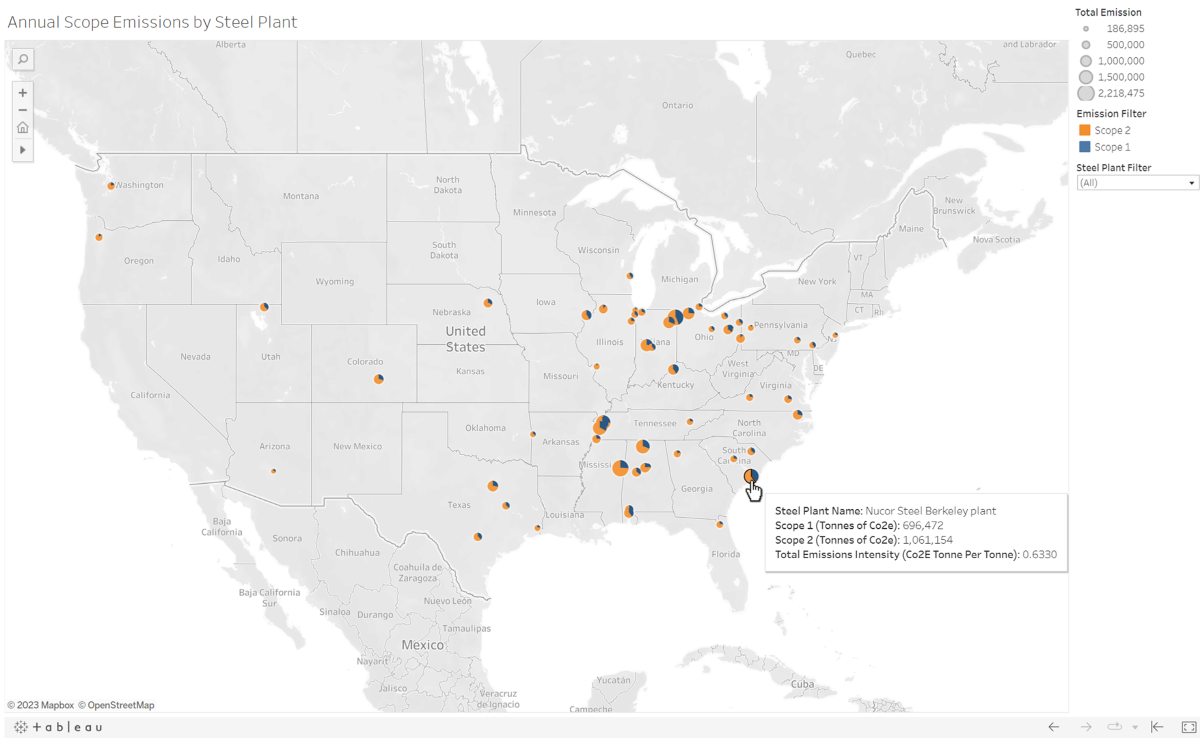

Figure 4 This map displays the 2021 Annual Scope Emissions by Steel Plant. The pie charts for each plant display the ratio of Scope 2 (in orange) to Scope 1 (in blue) emissions.

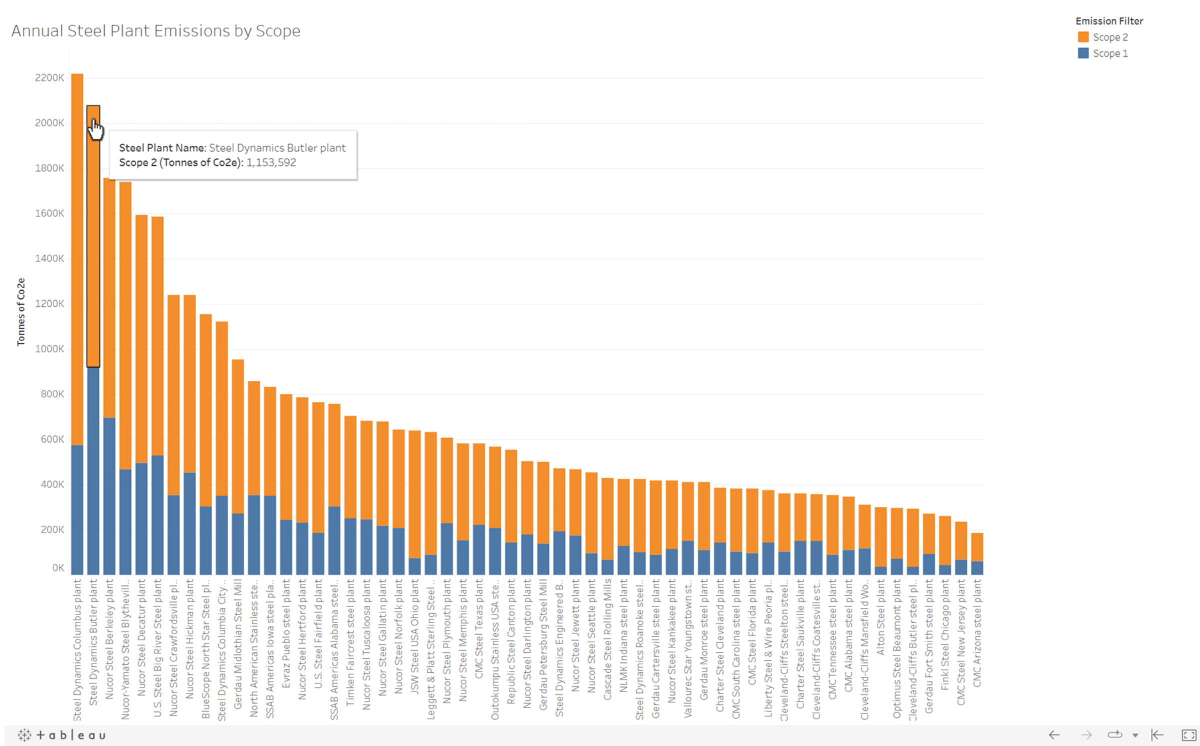

Figure 5 This bar chart displays the details of Scope 1 and Scope 2 emissions of each steel plant.

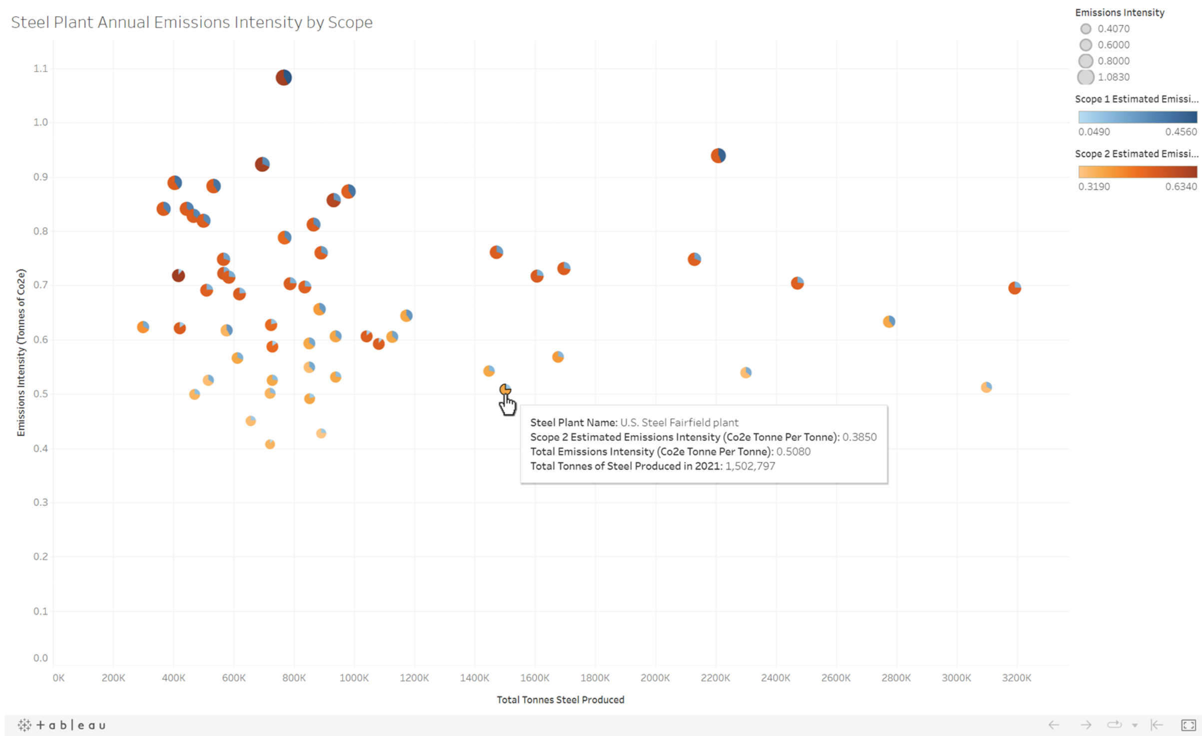

Figure 6 This scatterplot displays steel plant 2021 annual emissions intensity by Scope 1 and Scope 2 emissions.

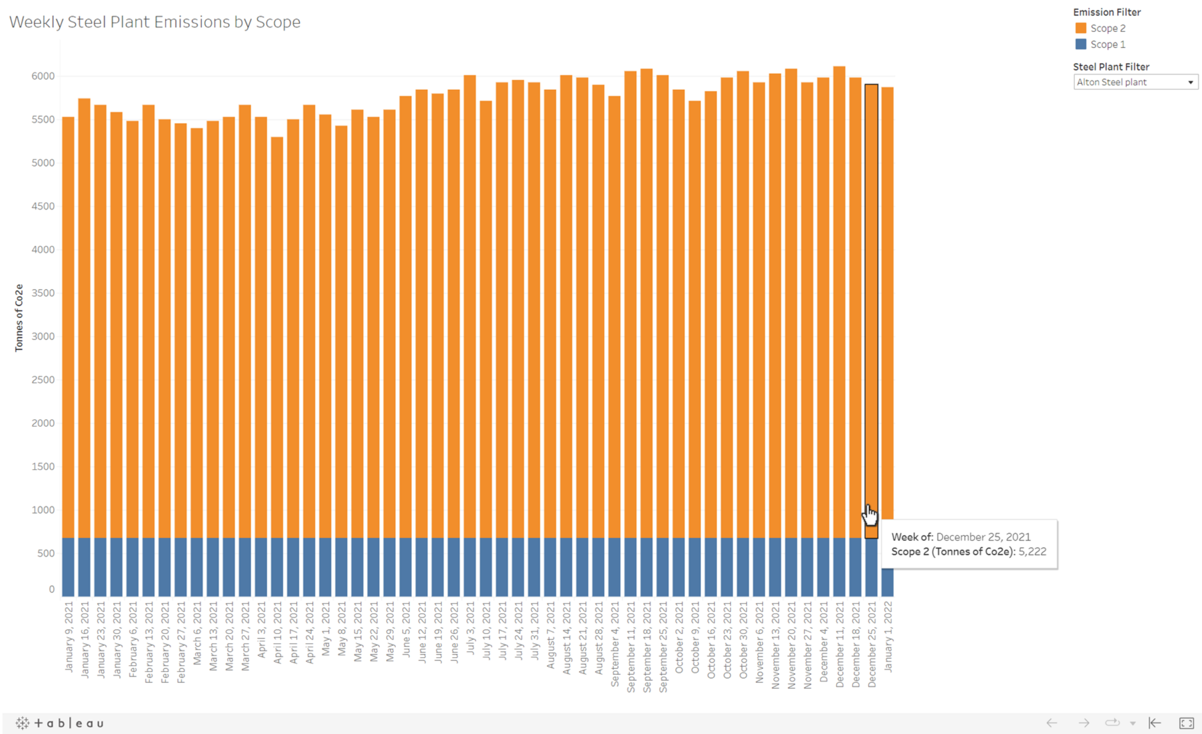

Figure 7 This bar chart shows the weekly breakdown of Scope 1 and Scope 2 emissions of the selected steel plant Alton Steel plant. In the dashboard, users can select to view any individual plant.

Summary of Testing

To ensure deliverables are robust, the project team conducted plant-level checks to ensure accuracy and benchmarking calculations against other values published and accepted in the industry. The Tableau dashboard was also tested by users to optimize clarity and functionality.

Code Testing

The initial joining of datasets and calculations were tested by each of the four members of the project team, ensuring that the R and Python code could be run to achieve the same results on multiple different devices. The team also ensured clear code by reviewing multiple times for clarity. Having four people run and review our code ensured accuracy in the critical data joining and cleaning process to create our dataset deliverable. Our calculations are simple to run on most R and Python versions and only require commonly installed libraries.

Reviewing Data Outputs

As a tidy dataset is a key deliverable in this project, ensuring that each steel plant represented in our output data had complete and accurate information was essential. This involved line-by-line checks of every plant. Plants with inconsistencies, incomplete information, or values that fell outside of the expected range were flagged for discussion. The project team discussed oddities in the output data with the client at GEM to determine why those anomalies occurred and how to deal with them. For example, some steel plants marked as operational in 2023 were on strike or temporary hiatus in 2021, meaning that the production and carbon emissions were 0 in 2021. Plants that had special cases like this were noted so that they could be displayed with a special note in the Tableau dashboard. Notes were also included in the metadata so users of our dataset in the future will understand the discrepancies. Details on these plants are listed in Appendix B.

User Testing

The client tested the Tableau public dashboard to ensure the functionality of our maps and visualizations meet their needs. The client was involved in an iterative design process to ensure that the carbon emission calculations are displayed clearly and in a way that supports GEM's mission. We also worked with our faculty advisor and solicited feedback from peers to ensure that the design and functionality of our dashboard was intuitive.

User Documentation

Users

Our users are primarily the GEM staff. Our secondary users include GEM's users, collaborators, and stakeholders such as the World Steel Association, journalists, researchers, and industry experts. The primary way in which we expect users to interact with our data is through the Tableau dashboard. This provides easy access to explore the data without any coding knowledge. The dashboard gives users the ability to visualize key trends and compares specific plants with Tableau's graphical user interface.

Workflow Reproducibility

This project is housed in the carbon-analysis repository on GitHub.[12] The 2021 Scope 1 emissions data downloaded from the EPA's Greenhouse Gas Reporting Program is saved in this repository for easy cloning and reproducibility. Client-provided data from GEM and AISI is available to the public, however users must request it directly from caitlin.swalec@globalenergymonitor.org at GEM to reproduce our analysis. The eGrid data which provides the emissions intensity of grid subregions is too large to store in the repository, but users can download emissions intensities of grid subregions directly from eGrid's data download page and the shapefiles from the eGrid mapping files page. The data sources needed to reproduce the calculations are linked in the table below.

[12] Bishop, Erica, Ruth Enriquez, Amrit Sandhu, and Michael Zargari. "Steeltracker/Carbon-Analysis," June 2023. https://github.com/steeltracker/carbon-analysis/tree/main.

Key Variables	Source	Link to Access
Steel plant names, locations, and capacities	GEM	Email caitlin.swalec@globalenergymonitor.org
Regional capacity utilization rates	AISI	Email caitlin.swalec@globalenergymonitor.org
Grid energy intensity values	EPA eGrid	https://www.epa.gov/egrid/download-data
Grid subregion shapefiles	EPA eGrid	https://www.epa.gov/egrid/egrid-mapping-files
Scope 1 emissions	EPA FLIGHT	https://ghgdata.epa.gov/ghgp/main.do

Once users have downloaded the appropriate data, the GitHub repository can be forked and cloned, and the data read-in file paths changed to point to the appropriate data directories. Then users will be able to run the entire quarto markdown or Jupyter notebook to recreate the same Scope 2 emissions and emissions intensity values for each plant. Our project was created using 2021 data from all sources and 2020 eGrid shapefiles (as the 2021 shapefiles were not available at the time). For future years, if variable names change in the EPA or GEM provided data, then some updates may need to be made to column names to reflect the new inputs.

Updating the Dashboard

Our client can update this dataset and visualizations in the future by re-running our analysis on new data provided in the same format. By linking any new yearly data to the Tableau dashboard, the visualizations can be updated. Users, including our client, just need internet access to view the Tableau public dashboard on their browser of choice. The interface is very intuitive and does not require any coding knowledge. New Tableau dashboards can also be easily created from future years of data with no coding knowledge.

Archive Access

Users have access to the GitHub repository to fork and download the code to do further analysis. All the data used in this analysis is publicly available, and we have credited and linked to the original sources. Instructions on how to download the data and set up a directory to reproduce our analysis are included in the README file in the GitHub repository.

References

American Iron and Steel Institute. “Steel Production,” 2023. https://www.steel.org/steel-technology/steel-production/.

Gamage, Chathurika, Kaitlyn Ramirez, Nick Yavorsky, and Lachlan Wright. “Forging a Clean Steel Economy in the United States.” RMI, March 9, 2023. https://rmi.org/forging-a-clean-steel-economy-in-the-united-states.

Hasanbeigi, Ali. “Steel Climate Impact.” Global Efficiency Intelligence, 2022. https://www.globalefficiencyintel.com/steel-climate-impact-international-benchmarking-energy-co2-intensities.

Hasanbeigi, Ali, and Adam Sibal. “What Is Green Steel? Definitions and Scopes from Standards, Protocols, Initiatives, and Policies around the World.” Global Efficiency Intelligence, 2023. https://www.globalefficiencyintel.com/what-is-green-steel.

“Sustainability Report 2021.” Cleveland-Cliffs Inc., 2021. https://d1io3yog0oux5.cloudfront.net/_c8bc841bcb126ca3e376a300c5b8abc0/clevelandcliffs/db/1188/11273/file/CLF_Report_Sustainability_2021_SinglePages.pdf.

World Steel Association. “World Steel in Figures 2022,” n.d. https://worldsteel.org/steel-topics/statistics/world-steel-in-figures-2022/#major-steel-producing-countries-2021-and-2020.

Appendix A: Metadata

2021_steel_plant_emissions_and_productions

Variable Name	Unit (if applicable)	Original dataset	Brief Description
plant_id		GEM_2022_data	An ID number formulated and assigned to each plant by GEM
ghgrp_id		GHG_flight_scope1	An ID number formulated and assigned to each plant by the EPA Greenhouse Gas Reporting Program
plant_name		GEM_2022_data	Name of the plant in the United States
owner		GEM_2022_data	Company that owns the plant
lat	latitude (degrees)	GEM_2022_data	The latitude of the plant location
lon	longitude (degrees)	GEM_2022_data	The longitude of the plant location
state		GEM_2022_data	The state the plant is located in
plant_age_years		GEM_2022_data	The age of the plant
municipality		GEM_2022_data	The municipality the plant is located in
address		GEM_2022_data	The address provided by steel plants for plant locations
category_steel_product		GEM_2022_data	The category of steel products produced
steel_products		GEM_2022_data	The specific steel products produced
subregion		egrid2020_subregions	Acronyms for each eGrid subregion. Each of the plants can be classified under one of the 27

			eGrid subregions
subregion_name		egrid2020_subregions	Full name for reach eGrid subregion. Each of the plants can be classified under one of the 27 eGrid subregions
co2e_tonnes_per_mwh	Metric tons of CO2e per MWh (per grid location)	egrid2020_subregions	The amount of carbon dioxide equivalent produced per megawatt hour of electricity produced for each eGrid grid location
region		AISI_data	The plants are categorized into one of the following AISI regions: North East, Great Lakes, Midwest, Southern, and Western
estimated_emissions_intensity_tonne_per_tonne_scope1	Metric tons of CO2e per metric tons of steel		The estimated amount of Scope 1 co2e (in metric tons) produced per metric ton of steel produced
estimated_emissions_intensity_tonne_per_tonne_scope2	Metric tons of CO2e per metric tons of steel		The estimated amount of Scope 2 co2e (in metric tons) produced per metric ton of steel produced
emissions_intensity_co2e_tonne_per_tonne	Metric tons of CO2e per metric tons of steel		Metric tons of CO2e produced per metric ton of steel produced
max_tonnes_of_steel_producible_annually	Metric tons of steel per year	GEM_2022_data	The total amount of steel that may be produced if the plant ran at 100%
max_tonnes_of_steel_producible_weekly	Metric tons of steel per week		The total amount of steel that may be produced if the plant ran at 100% per week (divide annual amount by 52)
scope1_co2e_tonnes_2021	Metric tons of CO2e per metric tons of steel	GHG_flight_scope1	Scope 1 total CO2e produced per year per plant
scope2_co2e_tonnes_2021	Metric tons of CO2e per metric tons of steel		Scope 2 total CO2e produced per year per plant

total_co2e_tonnes_2021	Metric tons of CO2e per metric tons of steel		Combined Scope 1 and Scope 2 CO2e produced per year per plant

weekly_steel_production

Variable Name	Unit (if applicable)	Original dataset	Brief Description
plant_id		GEM_2022_data	An ID number formulated and assigned to each plant by GEM
plant_name		GEM_2022_data	Name of the plant in the United States
owner		GEM_2022_data	Company that owns the plant
lat	latitude (degrees)	GEM_2022_data	The latitude of the plant location
lon	longitude (degrees)	GEM_2022_data	The longitude of the plant location
state		GEM_2022_data	The state the plant is located in
plant_age_years		GEM_2022_data	The age of the plant
municipality		GEM_2022_data	The municipality the plant is located in
address		GEM_2022_data	The address provided by steel plants for plant locations
category_steel_product		GEM_2022_data	The category of steel products produced
steel_products		GEM_2022_data	The specific steel products produced
subregion		egrid2020_subregions	Acronyms for each eGrid subregion. Each of the plants can be classified under one of the 27 eGrid subregions
subregion_name		egrid2020_subregions	Full name for reach eGrid subregion. Each of the plants can be classified under one of the 27 eGrid subregions
co2e_tonnes_per_mwh	Metric tons of CO2e per MWh (per grid location)	egrid2020_subregions	The amount of carbon dioxide equivalent produced per megawatt hour of electricity produced for each eGrid grid location

region		AISI_data	The plants are categorized into one of the following AISI regions: North East, Great Lakes, Midwest, Southern, and Western
estimated_emissions_intensity_tonne_per_tonne_scope2	Metric tons of CO2e per metric tons of steel		The estimated amount of Scope 2 co2e (in metric tons) produced per metric ton of steel produced
max_tonnes_of_steel_producible_annually	Metric tons of steel per year	GEM_2022_data	The total amount of steel that may be produced if the plant ran at 100%
max_tonnes_of_steel_producible_weekly	Metric tons of steel per week		The total amount of steel that may be produced if the plant ran at 100% per week (divide annual amount by 52)
week_end_dates*	Metric tons of steel per week (1/3/2021 to 1/1/2022)		Total metric tons of steel produced per week

weekly_scope1_scope2_steel_plant_emissions_2021

Variable Name	Unit (if applicable)	Original dataset	Brief Description
plant_id		GEM_2022_data	An ID number formulated and assigned to each plant by GEM
ghgrp_id		GHG_flight_scope1	An ID number formulated and assigned to each plant by the EPA Greenhouse Gas Reporting Program
plant_name		GEM_2022_data	Name of the plant in the United States
lat	latitude (degrees)	GEM_2022_data	The latitude of the plant location
lon	longitude (degrees)	GEM_2022_data	The longitude of the plant location
address		GEM_2022_data	The address provided by steel plants for plant locations
owner		GEM_2022_data	Company that owns the plant
state		GEM_2022_data	The state the plant is located in
plant_age_years		GEM_2022_data	The age of the plant
municipality		GEM_2022_data	The municipality the plant is located in
category_steel_product		GEM_2022_data	The category of steel products produced
steel_products		GEM_2022_data	The specific steel products produced
subregion		egrid2020_subregions	Acronyms for each eGrid subregion. Each of the plants can be classified under one of the 27 eGrid subregions
subregion_name		egrid2020_subregions	Full name for reach eGrid subregion. Each of the plants can be classified under one of the 27 eGrid subregions

region		AISI_data	The plants are categorized into one of the following AISI regions: North East, Great Lakes, Midwest, Southern, and Western
co2e_tonnes_per_mwh	Metric tons of CO2e per MWh (per grid location)	egrid2020_subregions	The amount of carbon dioxide equivalent produced per megawatt hour of electricity produced for each eGrid grid location
estimated_emissions_intensity_tonne_per_tonne_scope2	Metric tons of CO2e per metric tons of steel		The estimated amount of Scope 2 co2e (in metric tons) produced per metric ton of steel produced
max_tonnes_of_steel_producible_annually	Metric tons of steel per year	GEM_2022_data	The total amount of steel that may be produced if the plant ran at 100%
max_tonnes_of_steel_producible_weekly	Metric tons of steel per week		The total amount of steel that may be produced if the plant ran at 100% per week (divide annual amount by 52)
scope1_tonnes_of_co2e_per_week	Metric tons of CO2e per week		Annual Scope 1 data divided by 52 weeks in order to give us Scope 1 data per week
week_end_dates*	Metric tons of CO2e per week (1/3/2021 to 1/1/2022)		Total Scope 1 and Scope 2 metric tons of CO2e produced per week

weekly_scope2_steel_plant_emissions_2021

Variable Name	Unit (if applicable)	Original dataset	Brief Description
plant_id		GEM_2022_data	An ID number formulated and assigned to each plant by GEM
ghgrp_id		GHG_flight_scope1	An ID number formulated and assigned to each plant by the EPA Greenhouse Gas Reporting Program
plant_name		GEM_2022_data	Name of the plant in the United States
lat	latitude (degrees)	GEM_2022_data	The latitude of the plant location
lon	longitude (degrees)	GEM_2022_data	The longitude of the plant location
address		GEM_2022_data	The address provided by steel plants for plant locations
owner		GEM_2022_data	Company that owns the plant
state		GEM_2022_data	The state the plant is located in
plant_age_years		GEM_2022_data	The age of the plant
municipality		GEM_2022_data	The municipality the plant is located in
category_steel_product		GEM_2022_data	The category of steel products produced
steel_products		GEM_2022_data	The specific steel products produced
subregion		egrid2020_subregions	Acronyms for each eGrid subregion. Each of the plants can be classified under one of the 27 eGrid subregions
subregion_name		egrid2020_subregions	Full name for reach eGrid subregion. Each of the plants can be classified under one of the 27 eGrid subregions

region		AISI_data	The plants are categorized into one of the following AISI regions: North East, Great Lakes, Midwest, Southern, and Western
co2e_tonnes_per_mwh	Metric tons of CO2e per MWh (per grid location)	egrid2020_subregions	The amount of carbon dioxide equivalent produced per megawatt hour of electricity produced for each eGrid grid location
estimated_emissions_intensity_tonne_per_tonne_scope2	Metric tons of CO2e per metric tons of steel		The estimated amount of Scope 2 co2e (in metric tons) produced per metric ton of steel produced
max_tonnes_of_steel_producible_annually	Metric tons of steel per year	GEM_2022_data	The total amount of steel that may be produced if the plant ran at 100%
max_tonnes_of_steel_producible_weekly	Metric tons of steel per week		The total amount of steel that may be produced if the plant ran at 100% per week (divide annual amount by 52)
week_end_dates*	Metric tons of CO2e per week (1/3/2021 to 1/1/2022)		Total Scope 2 metric tons of CO2e produced per week

Appendix B: Steel Plant Notes

The dataset we produced with calculated Scope 1 and Scope 2 CO_2e values includes (X) plants with NA values. Below are explanations to these NA values, where available.

Plant_ID SUS00037 - address mismatch flight to GEM. We are electing to keep the GEM address. The FLIGHT address is 1 Thyssenkrupp Drive, Clavert AL. Same location, different addresses.

PLANT ID_SUS00038
Comment: Address difference, but same plant name
GEM: 3707 Georgetown St. N.E., Canton, Ohio 44704
GHG: 2633 EIGHTH STREET NE

PLANT ID_SUS00045
Comment: the GHG has the headquarter address, GEM has the actual plant address, we are assuming the Scope 1 emissions is for the plant
GEM: 4511 Faircrest St. SW, Canton, Ohio 44706, United States
GHG: 1835 DUEBER AVENUE, S.W.

PLANT ID_SUS00002
Comment: city and zip code mismatch because the city doesn't match, GHG has it incorrectly
GEM: 1 Armco Dr, Lyndora, PA 16045-1065, United States
GHG: 1 ARMCO DR, BUTLER

PLANT ID_SUS00007
correct zip code is GHG with 19320

PLANT ID_SUS00015
GEM has this one right, GHG has the wrong zip.
25801 HOFHEIMER WAY 23803 (correct is 23805)

PLANT ID_SUS00061
Didn't match even though zip codes are the same.
420 S Hazard St, Georgetown, SC 29440, United States

Appendix C: Documentation of Assumptions

There is currently no comprehensive, public information available on the Scope 2 emissions of steel production in the United States. This is partly because the steel industry keeps much of its data private. To overcome this challenge of critical data being unavailable, we made several key assumptions to make our calculations. These assumptions were made under the guidance of our faculty advisor and in consultation with our client. We believe that although these assumptions make generalizations that may not hold for each individual plant, they are useful in providing transparency where it is needed.

Assumptions:

1. Every EAF steel plant in our data set is assumed to be powered entirely by electricity drawn from the electric grid with no supplementary on-site generation. This is not the case for every plant, but it was a critical assumption for obtaining the emissions intensity of the electricity for these plants.
2. The energy intensity of EAF steel production in the US is assumed to be 710 kWh per tonne. This number is proved in Industrial Electrification in U.S. States: An industrial subsector and state-level techno-economic analysis by Ali Hasanbeigi, Global Efficiency Intelligence, and Lynn Kirshbaum and Blain Collison from David Gardiner and Associates. This energy intensity figure accounts for casting, rolling, and finishing steps. However, it excludes thermal demand.
3. EAF steel plant emissions and emissions intensities are calculated under the assumption that plants are using 100% scrap inputs. Direct-reduced iron (DRI) inputs at the plant increase the energy requirements and the emissions values. Sufficient data was not available to include this in the analysis.
4. Weekly Scope 1 emissions were calculated by a simple division of the annual Scope 1 emissions by 52 (the number of weeks available in the dataset). This is an imperfect method, but without more weekly data the simplest approach was taken.
5. The annual grid emissions intensity for electricity production in the eGrid data was also divided by 52 to get an approximation for weekly values. Given the scope of this project, the annual emissions intensity data was the best available to us, but this makes the weekly emissions values less accurate than the annual emissions calculations.
6. For total production, the reported regional utilization rates and total capacity are assumed to be correct, thus the annual production for each plant is just these two values multiplied.