Consumption-based Emissions Rates for eGRID

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Introduction

Why characterize emissions associated with electricity generation?

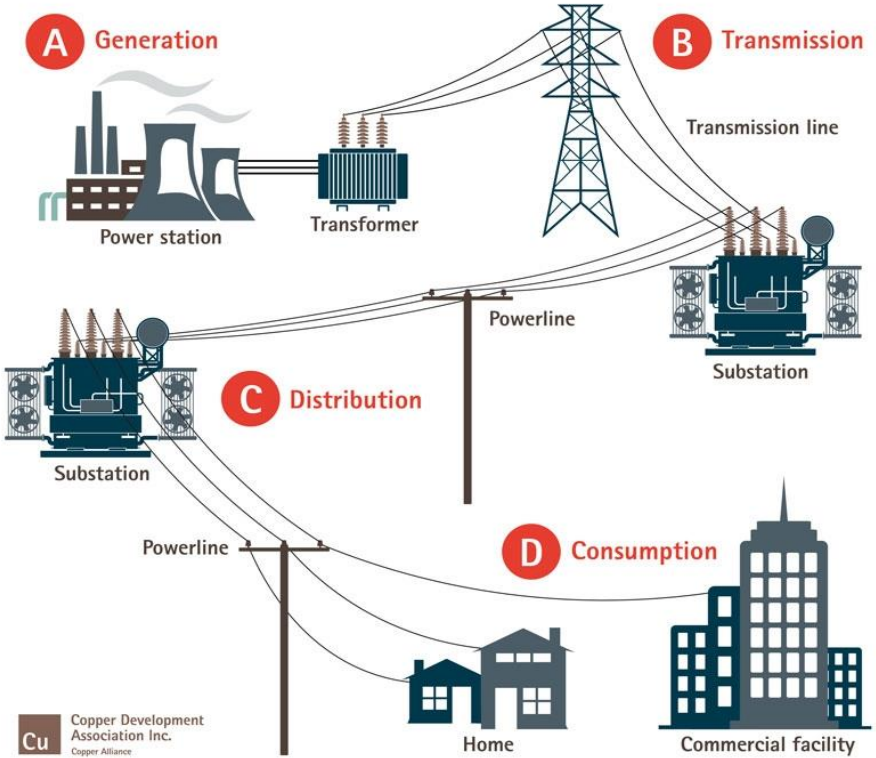
- ❑ Environmental Impact
- ❑ Policy and Regulation
- ❑ Energy Transition
- ❑ Resource Allocation
- ❑ Public Awareness

Georgia Power Co.'s Plant Sherer (Source: Georgia Power). Largest coal fired plant and the largest single point source emitter of greenhouse gas (GHG) emissions in the U.S., at over 20,000,000 short tons per year.

Introduction

The Electricity Grid

- Electricity generated at power plants moves through a complex networked infrastructure.
- In the United States, the power system consists of more than 7,300 power plants
- Nearly 160,000 miles of high-voltage power lines
- Millions of low-voltage power lines and distribution transformers
- Connects 145 million customers.

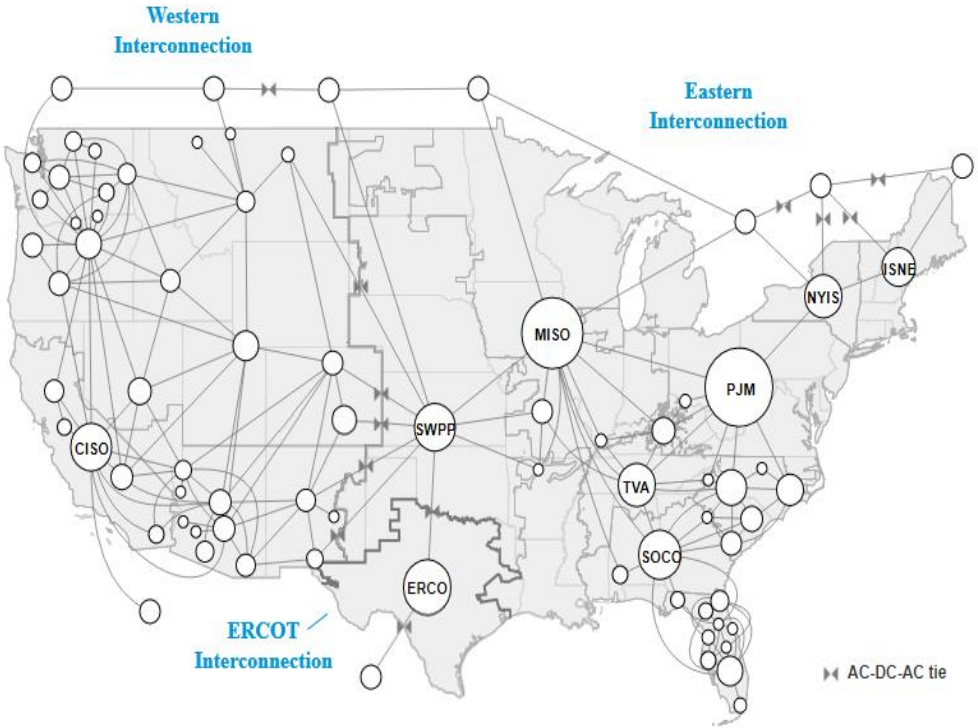


Source: Copper Development Association Inc.

Introduction

Balancing Authorities

- The actual operation of the electric system is managed by entities called balancing authorities.
- A balancing authority ensures, in real time, that power system demand and supply are finely balanced.
- Ensure a sufficient supply of electricity is available to serve expected demand.
- Managing transfers of electricity with other balancing authorities.

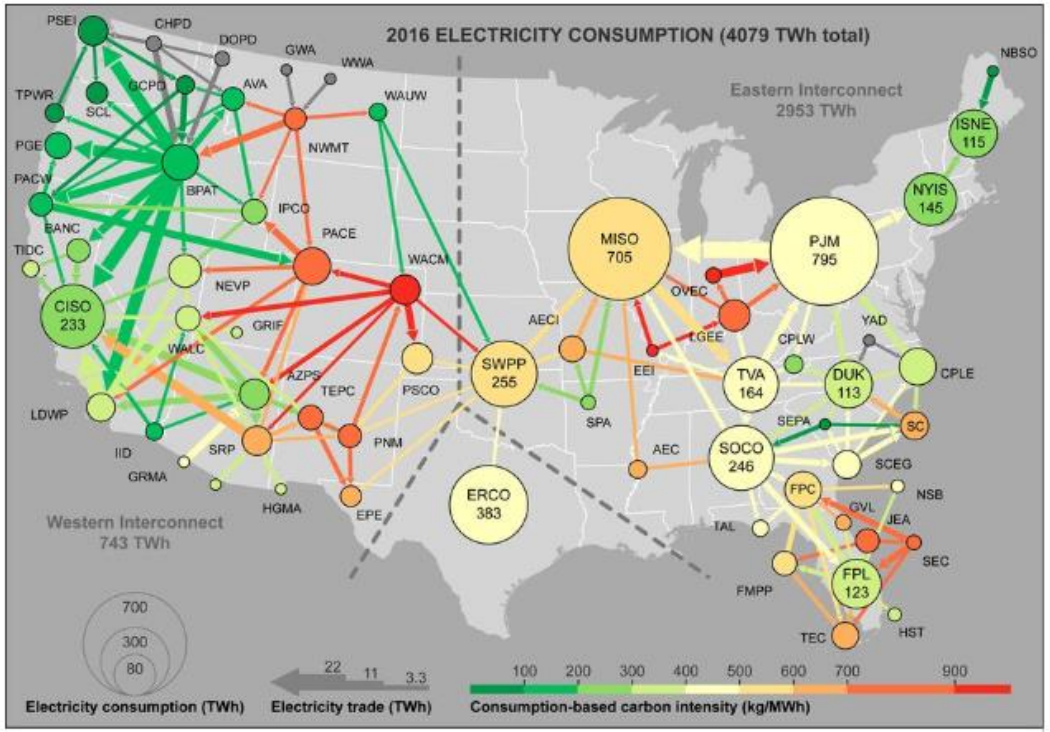


Source: Energy Information Administration

Introduction

Production vs Consumption based rates

- Production based emissions rates measure emissions occurring during power/electricity generation within specific regions.
- Consumption-based emissions refer to the emissions associated with the consumption of electricity, regardless of where those emissions occur in the supply chain.

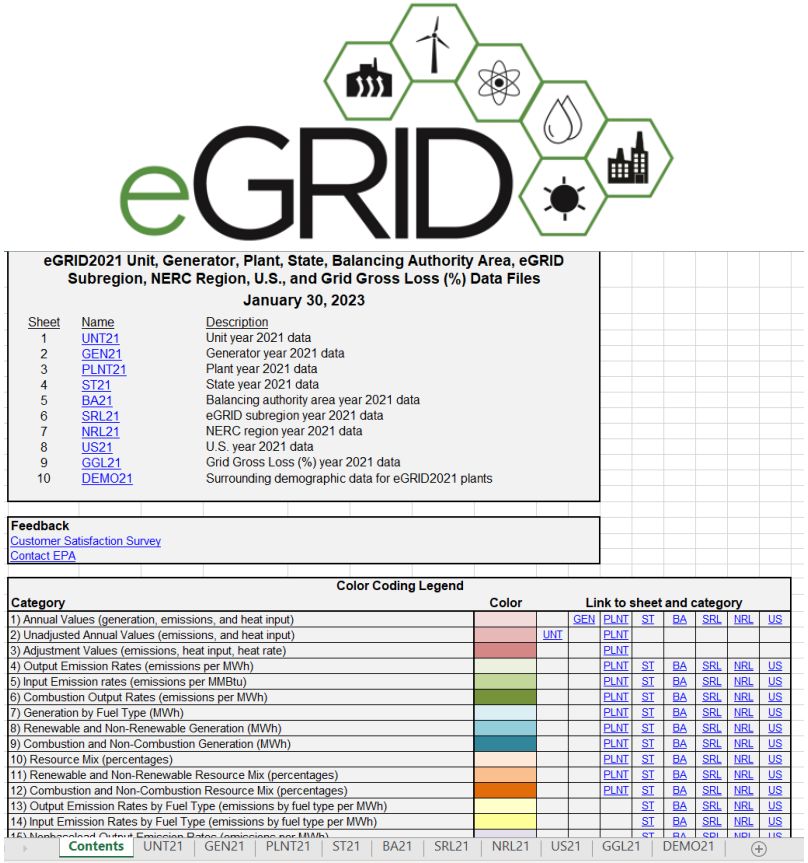


Source: Chalendar et al., 2019

What is eGRID?

eGRID (The Emissions & Generation Resource Integrated Database)

- Preeminent source of emissions data for the electric power sector in the U.S.
- Based on available plant-specific data for all U.S. electricity generating plants that provide power to the electric grid and report data to the U.S. government.
- Calculates emissions rates associated with the production of electricity at various aggregation levels including balancing authority.



eGRID2021 Unit, Generator, Plant, State, Balancing Authority Area, eGRID Subregion, NERC Region, U.S., and Grid Gross Loss (%) Data Files

January 30, 2023

Sheet	Name	Description
1	UNT21	Unit year 2021 data
2	GEN21	Generator year 2021 data
3	PLNT21	Plant year 2021 data
4	ST21	State year 2021 data
5	BA21	Balancing authority area year 2021 data
6	SRL21	eGRID subregion year 2021 data
7	NRL21	NERC region year 2021 data
8	US21	U.S. year 2021 data
9	GGL21	Grid Gross Loss (%) year 2021 data
10	DEMO21	Surrounding demographic data for eGRID2021 plants

Feedback

Customer Satisfaction Survey

Contact EPA

Color Coding Legend

Category	Color	Link to sheet and category							
1) Annual Values (generation, emissions, and heat input)			GEN	PLNT	ST	BA	SRL	NRL	US
2) Unadjusted Annual Values (emissions, and heat input)		UNT		PLNT					
3) Adjustment Values (emissions, heat input, heat rate)				PLNT					
4) Output Emission Rates (emissions per MWh)				PLNT	ST	BA	SRL	NRL	US
5) Input Emission rates (emissions per MMBtu)				PLNT	ST	BA	SRL	NRL	US
6) Combustion Output Rates (emissions per MWh)				PLNT	ST	BA	SRL	NRL	US
7) Generation by Fuel Type (MWh)				PLNT	ST	BA	SRL	NRL	US
8) Renewable and Non-Renewable Generation (MWh)				PLNT	ST	BA	SRL	NRL	US
9) Combustion and Non-Combustion Generation (MWh)				PLNT	ST	BA	SRL	NRL	US
10) Resource Mix (percentages)				PLNT	ST	BA	SRL	NRL	US
11) Renewable and Non-Renewable Resource Mix (percentages)				PLNT	ST	BA	SRL	NRL	US
12) Combustion and Non-Combustion Resource Mix (percentages)				PLNT	ST	BA	SRL	NRL	US
13) Output Emission Rates by Fuel Type (emissions by fuel type per MWh)					ST	BA	SRL	NRL	US
14) Input Emission Rates by Fuel Type (emissions by fuel type per MWh)					ST	BA	SRL	NRL	US
15) Nonbaseload Output Emission Rates (emissions per MWh)					ST	BA	SRL	NRL	US

Contents | UNT21 | GEN21 | PLNT21 | ST21 | BA21 | SRL21 | NRL21 | US21 | GGL21 | DEMO21

Consumption-based emissions rates

- The consumption-based emissions calculation approach is based on Chalendar et al., 2019.
- It utilizes multi-region input-output (MRIO) model to calculate consumption-based emissions for each balancing authority (BA).
- At each hour, the MRIO model solves a linear system that equates generated emissions to the sum of consumed emissions and interchanged emissions across all regions.
- The linear system is represented as: $x_i(p_i+U_i) - \sum_j(\_x_j u_{ij}) = f_i$
  - x_i: Consumed emission intensity in region i
  - p_i: Electricity produced in region i
  - U_i: Total import into region i
  - u_{ij}: Import from region j to region i
  - f_i: Total pollutant produced in region I
- Alternately, this system looks to balance production and import with consumption and export at each hour for each balancing authority
  p+U=d+V (where p is production, U is import, d is consumption and V is export)

Methods

- For each subregion in a balancing authority (BA): Substitute emission rate and aggregated subregion interchanges to relevant balancing authority

- Calculated consumption-based emission rates:

$$\text{Consumption} - \text{based Emission Rate}_{BA,t} = \frac{\left(\text{Generated energy that is consumed}_{BA,t} * \text{eGRID}_{BA}\right) + \sum_{N=1}^{\text{Tot}_{\text{Neighbors}^{Imp}}} (\text{Imports}_{N,t} * \text{eGRID}_{N})}{\text{Generated energy that is consumed}_{BA,t} + \sum_{N=1}^{\text{Tot}_{\text{Neighbors}^{Imp}}} (\text{Imports}_{N,t})}$$

Where:

Neighbors^{Imp}: every neighboring BA from which energy is imported at time t

$\text{Generated energy that is consumed}_{BA,t}$: As per EIA grid monitor's documentation, this is reported by each balancing authority on an hourly basis (MWh)

$\text{Imports}_{N,t}$: Imported energy at time t, from neighbor N (MWh)

eGRID_{N}: eGRID emission rate for neighbor N (lb/MWh)

eGRID_{BA}: eGRID emission rate for balancing authority BA (lb/MWh)

- These calculations are computed both at the hourly and annual time intervals.

Methods

Sample calculation - Total annual consumption-based CO_2 emission rate for CISO

CISO BA has 12 neighboring BAs in 2021 - AZPS, BANC, BPAT, CEN, CFE, IID, LDWP, NEVP, PACW, SRP, TIDC, and WALC

$$\sum_{h=1}^{8760} (Portion\ of\ generated\ electricity\ consumed\ at\ hour\ h \times eGRID\ reported\ CO_2\ emission\ rate\ for\ CISO)$$

The total annual CO_2 emissions attributed to the portion of generation consumed within CISO is **98, 684, 954, 111.65** pounds.

Next, the imported CO_2 emissions to CISO from neighboring BAs are calculated for each hour and summed to the annual level.

$$\sum_{h=1}^{8760} \sum_{Neighbor=1}^{12} Imported\ electricity\ from\ neighbor\ at\ hour\ h \times eGRID\ reported\ CO_2\ emission\ rate\ for\ neighbor$$

The total annual imported CO_2 emissions to CISO from neighboring BAs is **41, 191, 098, 592.0** pounds.

From EIA-930.
The annual sum of generated electricity consumed by CISO is **218, 517, 605** megawatt hours (MWh) and
The annual sum of imported electricity by CISO is **57, 943, 347** MWh.

Finally, the consumption-based emissions rate for CISO is calculated using the values outlined above.

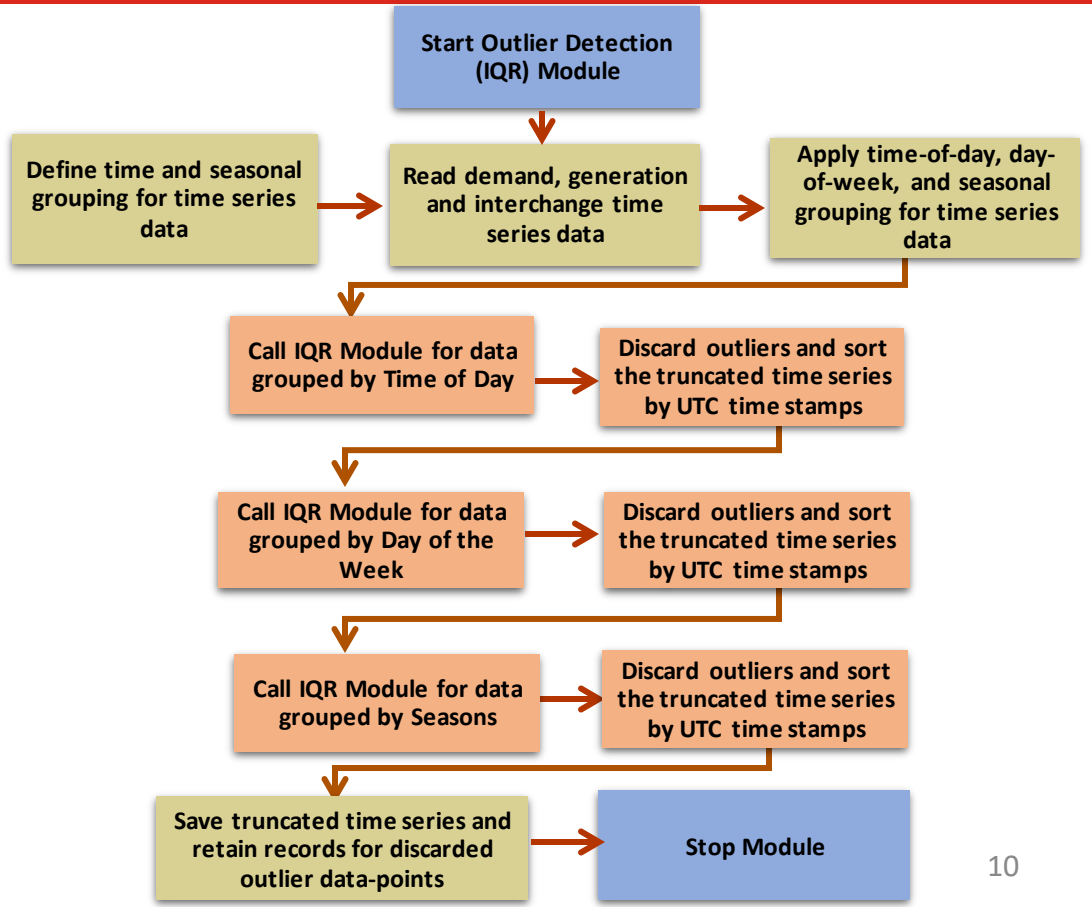
$$\frac{Annual\ emission\ attributed\ to\ generation\ that\ is\ consumed\ within\ CISO + Annual\ imported\ emissions}{Annual\ generation\ that\ is\ consumed\ within\ CISO + Annual\ imported\ electricity}$$

$$\frac{\mathbf{98,684,954,111.65\ lbs\ +\ 41,191,098,592.0 lbs}}{\mathbf{218,517,605 MWh + 57,943,347\ MWh}} = \mathbf{505.95\ lbs/MWh}$$

Methods

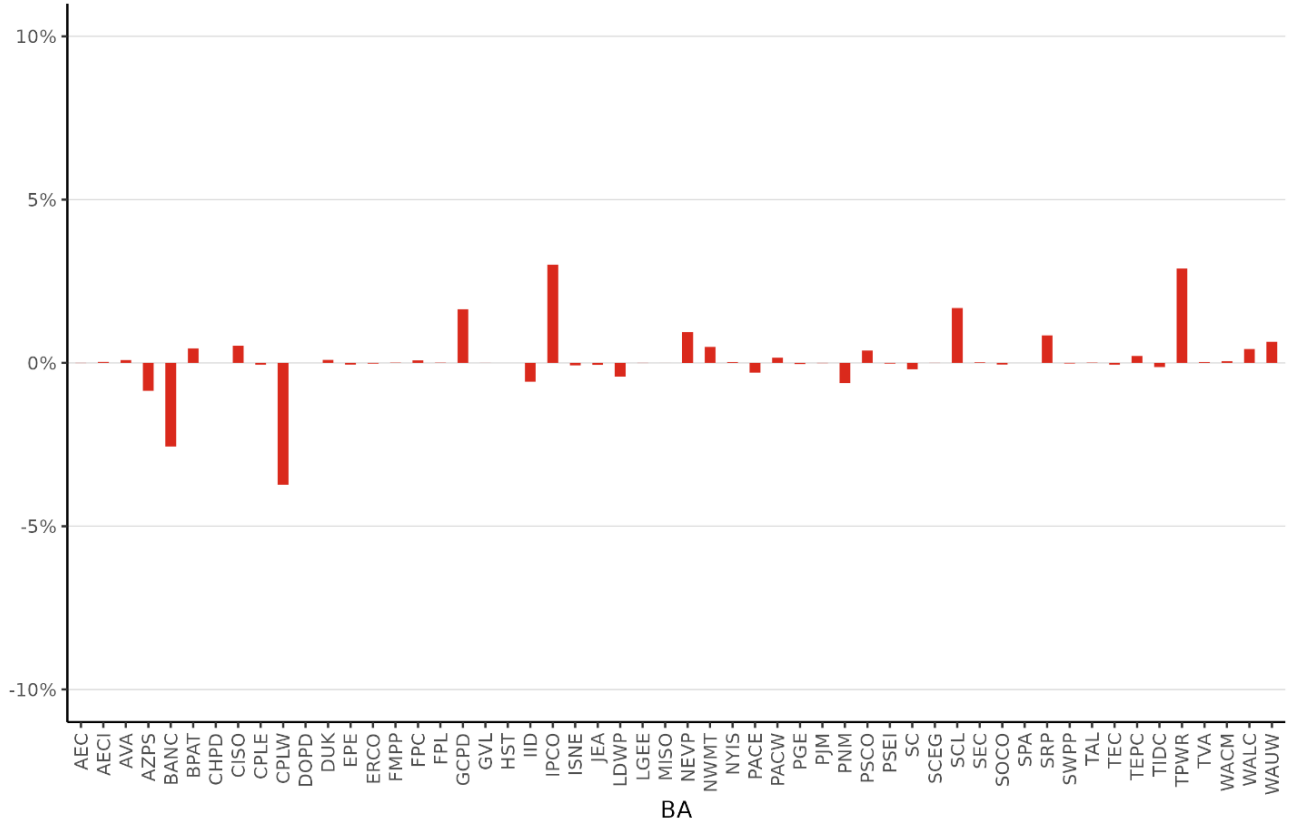
Outlier Detection

- Test approach involved removal of all outliers that were more than 1.5 x inter-quartile range (IQR) of the given time series of EIA-930 data
- Outlier detection was conducted with the consideration that time series variations differ with seasons, time of day, and day-of-the week
- The analysis indicated an absence of any major impacts from outliers
  - The comparison of median of hourly consumption-based CO_2 emission rates with and without outlier detection indicated **< 5% of difference** across all balancing authorities



Results- Outlier Detection

Fig.1 Percentage change in the consumption-based median hourly CO_2 emissions rates for all balancing authorities in 2021 after outlier removal.



Results - Consumption Based Rates

Fig.2 Comparison of production-based eGRID rates vs Consumption-based median hourly rates for balancing authorities with highest consumption-based rates for CO_2, SO_2, NOx, CH_4 respectively in 2021.

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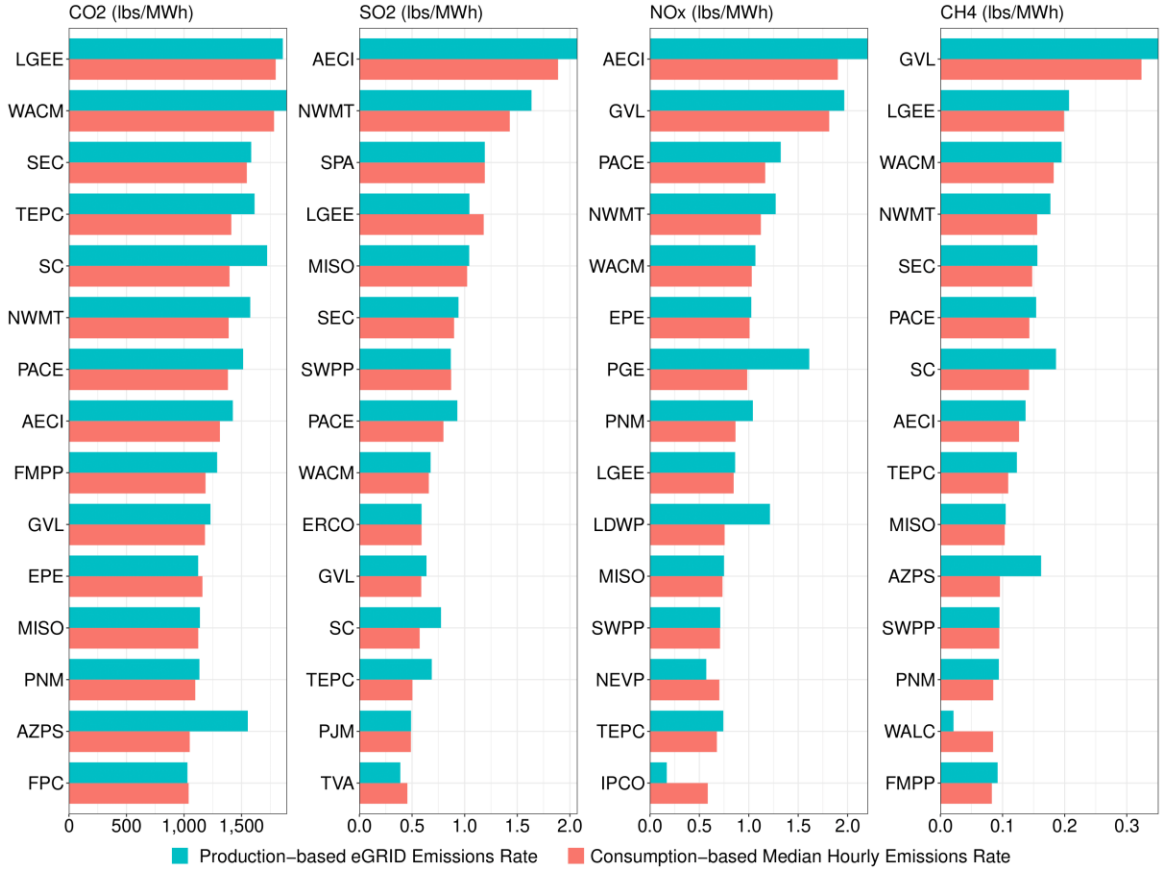

Results - Consumption Based Rates

Fig.3 Diurnal variation of the consumption-based CO_2 emissions rate for each season (figure shows median hourly consumption-based values for each season) and its comparison with the eGRID production-based rate for the balancing authority CISO (top) and MISO (bottom) in 2021.

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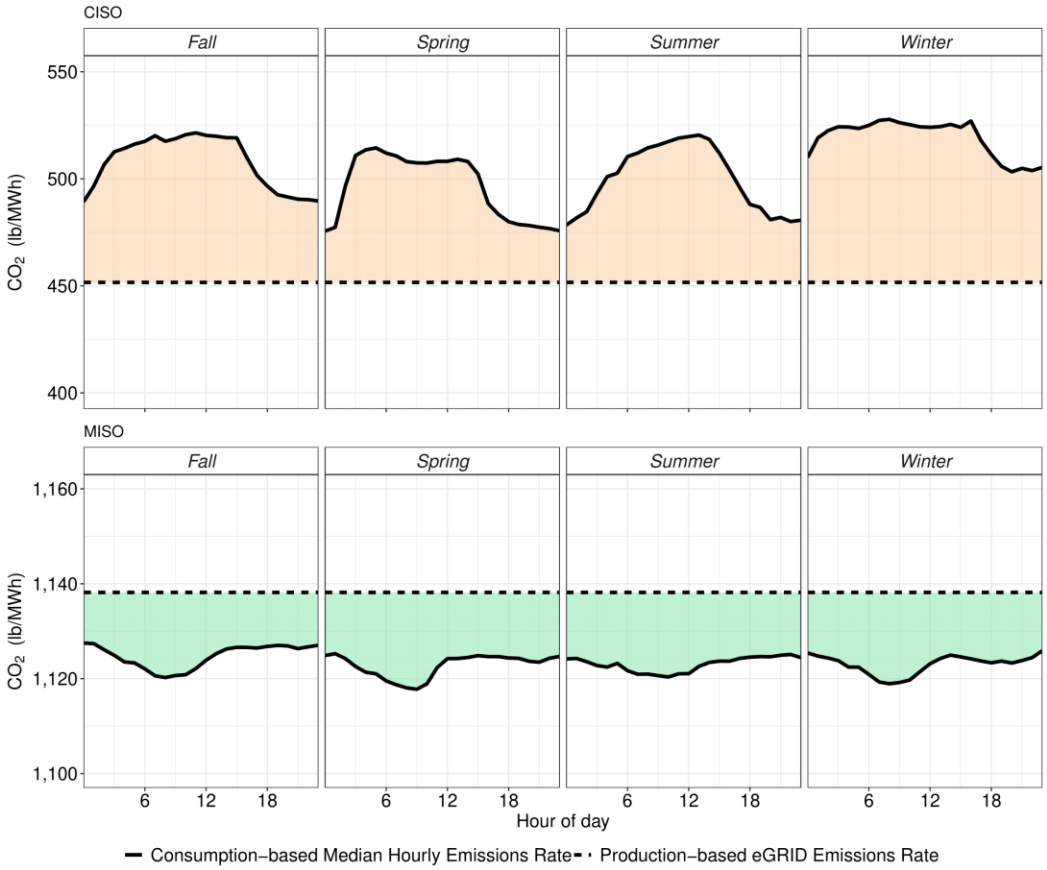
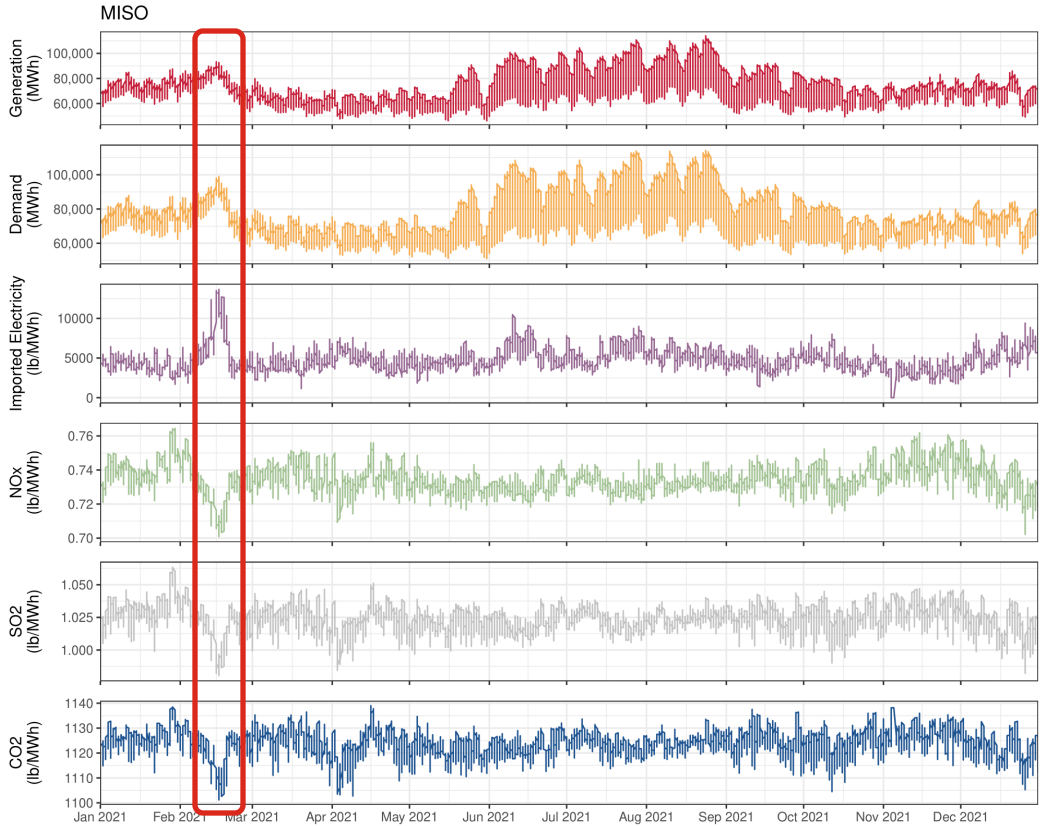


Results - Consumption Based Rates

Fig.4 Timeseries of hourly electricity generation, demand, imported electricity, consumption-based NOx, SO_2 and CO_2 emissions rates for MISO balancing authority in 2021.



Summary & Conclusions

- Calculating consumption-based emission rates at the BA level provides an indication of the emissions intensity of the consumption (or demand) of electricity within a particular region.
- Production-based emissions focus on where emissions physically occur due to electricity generation, while consumption-based emissions account for the environmental impact of a region's consumption characteristics, considering emissions embodied in imported goods and services.
- Initial results reveal that regions that generate dirty energy but import clean energy may have cleaner consumed emissions. Conversely, consumed emissions can be dirtier than generated emissions in regions that generate clean energy but import energy from their neighbors.
- Preliminary results highlight the importance of consumption-based rates in the holistic assessment of environmental impacts of electricity generation and consumption for informed policy making.

Next Steps

- Improvement in the consumption-based emissions calculations in future
  - Data inputs for foreign BAs that exchange energy with U.S. BAs.
  - Refined information on consumed fuel mix.
  - Detailed data on transmission infrastructure and operational constraints
  - Accounting for transmission losses in consumed emission calculations.
  - Improved outlier detection and data cleaning from sources such as EIA-930.
- Releasing consumption-based rates with future eGRID releases.
- Exploring the complementary nature of production and consumption-based rates.

Special Thanks

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Thank You!

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