

ElectricityEmissions.jl

Calculating carbon intensity signals on the power grid

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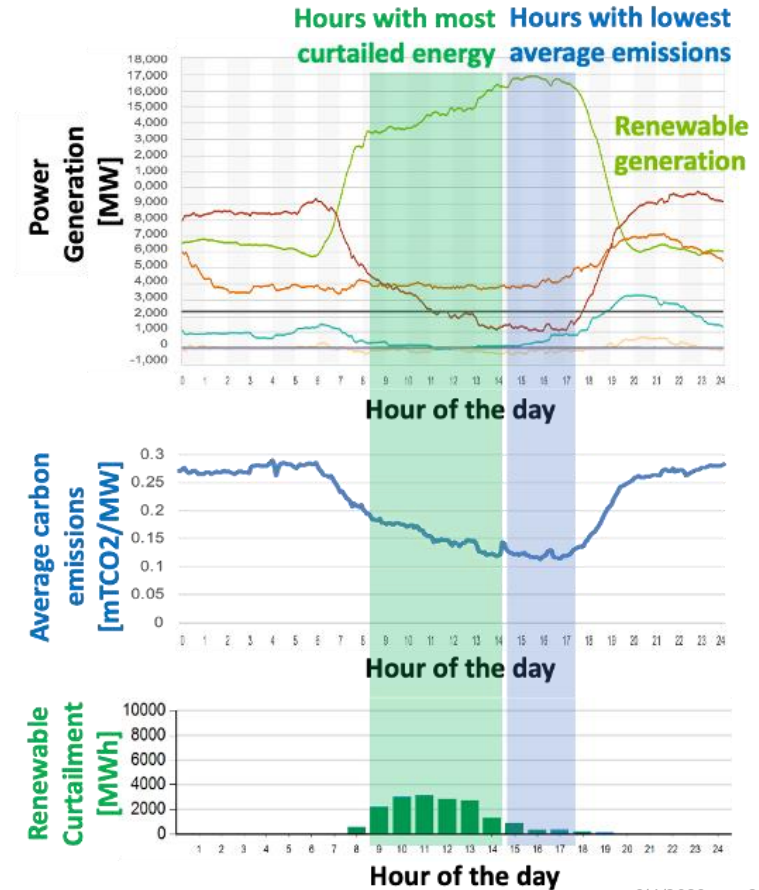
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Carbon Emissions Metrics

- How much CO₂ does my electricity consumption produce?
 - Scope 2 emissions
 - Carbon Accounting
- If I change my electricity consumption, how will carbon emissions change?
 - Impact on changing emissions

Gorka, J., Rhodes, N., & Roald, L. (2025, June). Electricityemissions.jl: A framework for the comparison of carbon intensity signals. In *Proceedings of the 16th ACM International Conference on Future and Sustainable Energy Systems* (pp. 19-30).

CAISO Energy Supply and Carbon Emissions
(June 10, 2021)

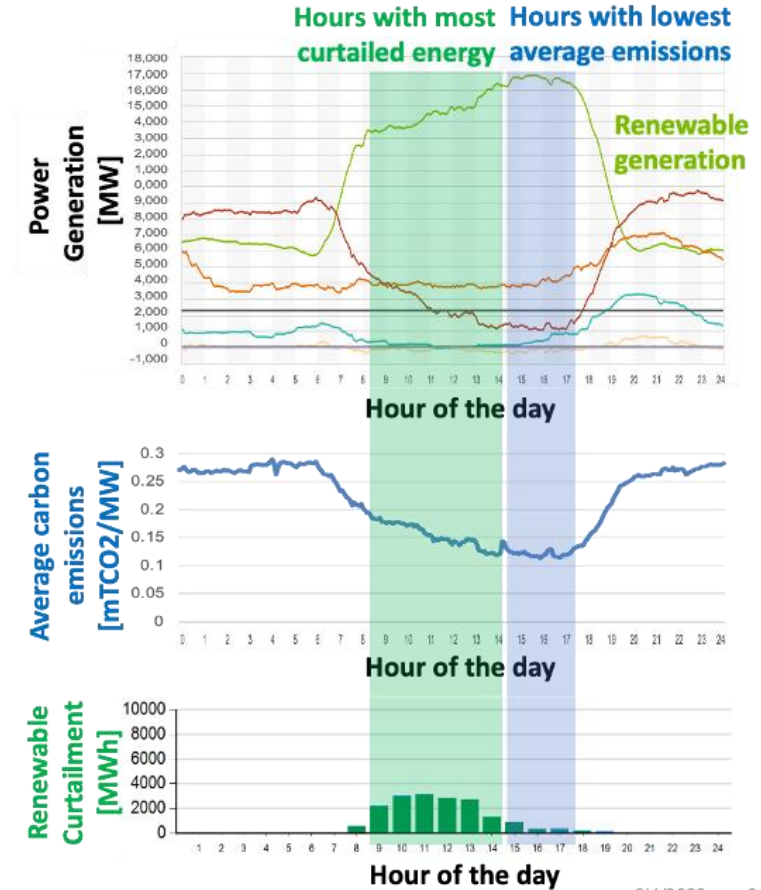


Location Marginal Carbon Emissions

- Sensitivity of carbon emissions to changes in load at a node
- Analogous to Locational Marginal Prices

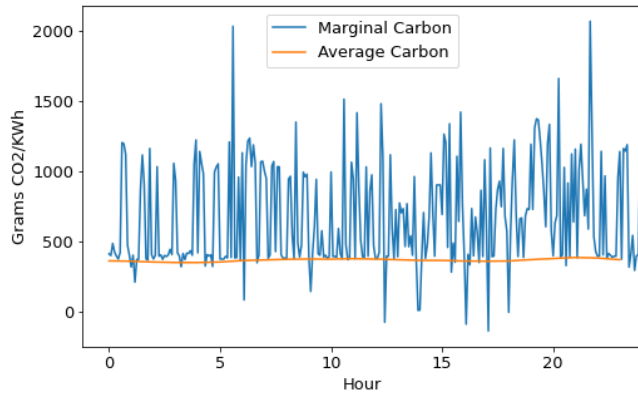
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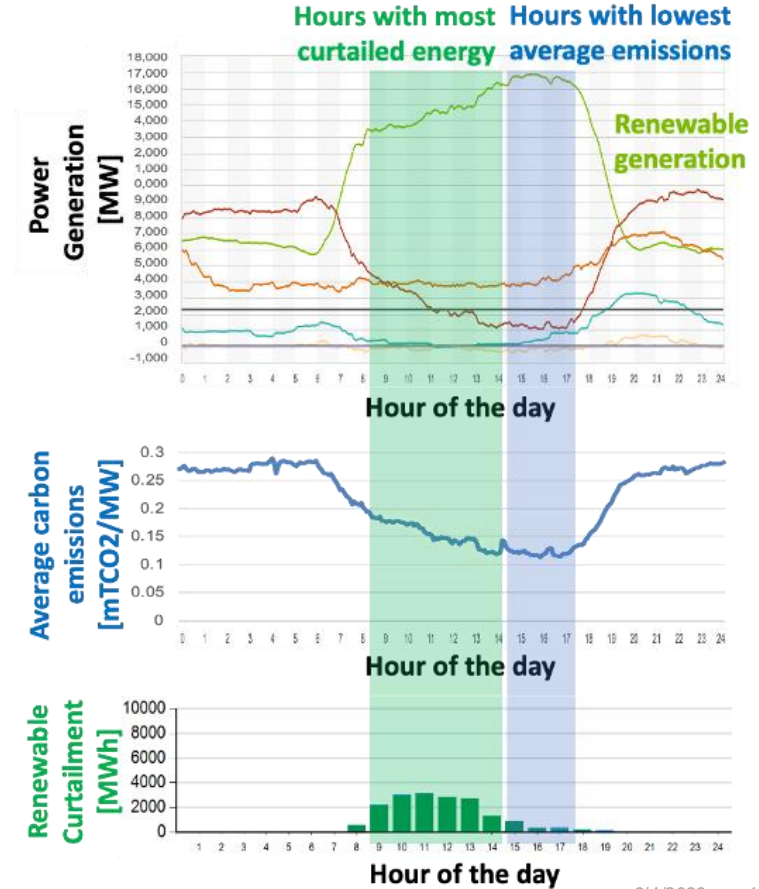
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CAISO Energy Supply and Carbon Emissions (June 10, 2021)



Different metrics

- Average Carbon Emissions (ACE)
$$e_{D,t}^{avg} = \frac{E_{G,t}^{tot}}{\sum_{j \in \mathcal{D}} p_{D,j,t}}$$
- Locational Marginal Carbon Emissions (LMCE)
$$e_{D,j,t}^{lmce} = \frac{\delta E_{G,t}^{tot}}{\delta p_{D,j,t}}$$
- Adjusted LMCE (ALMCE)
$$e_{D,j,t}^{almce} = e_{D,j,t}^{lmce} + \frac{E_{G,t}^{tot} - E_{D,t}^{lmce}}{\sum_{j \in \mathcal{D}} p_{D,j,t}}$$
- Locational Average Carbon Emissions (LACE)
 - ‘Traces’ power flow to assign emissions intensity

ElectricityEmissions.jl

- Package to calculate emissions metrics for power grid networks
- Modeled with JuMP, allows to easily extract dual values, active constraints, for computing metrics

```
using PowerModels, ElectricityEmissions
using HiGHS

# Load the network data with generator emissions intensity
network = PowerModels.parse_file("case5_gen_intensity.m")

# Calculate carbon intensities (solves a PWL DC OPF problem)
lmce = calculate_LMCE(network, HiGHS.Optimizer)
almce = calculate_ALMCE(network, HiGHS.Optimizer)
ace = calculate_ACE(network, HiGHS.Optimizer)
lace = calculate_LACE(network, HiGHS.Optimizer)

# Calculate total system emissions
total_emissions = calculate_system_emissions(network, HiGHS.Optimizer)

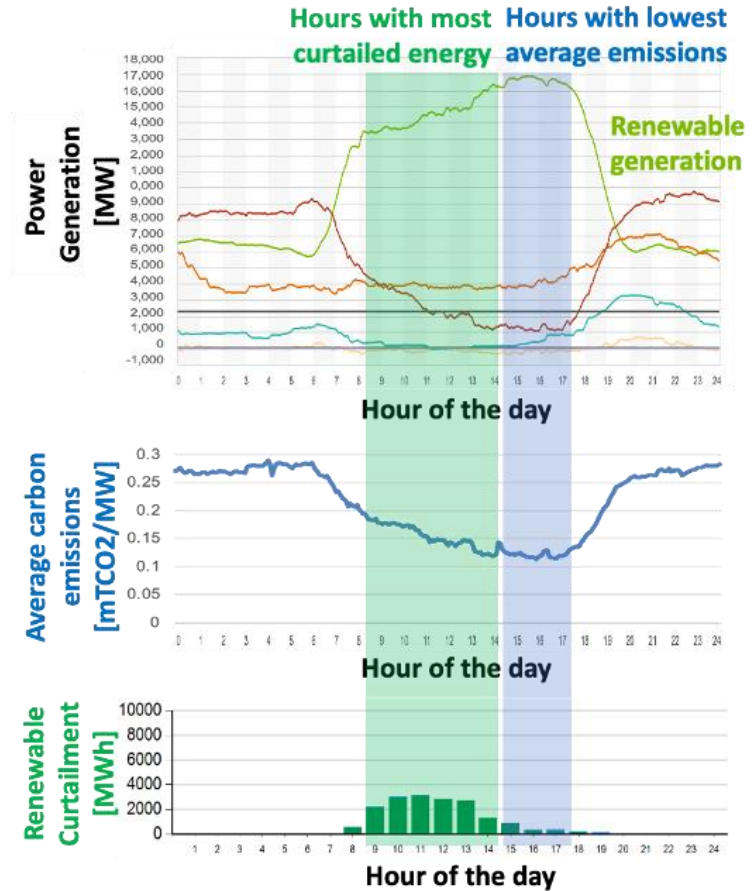
# Plot network with carbon intensity data

# Update network data with chosen emissions intensity
update_emissions_intensity!(network, lmce)
```

Utilizing Emissions Metrics

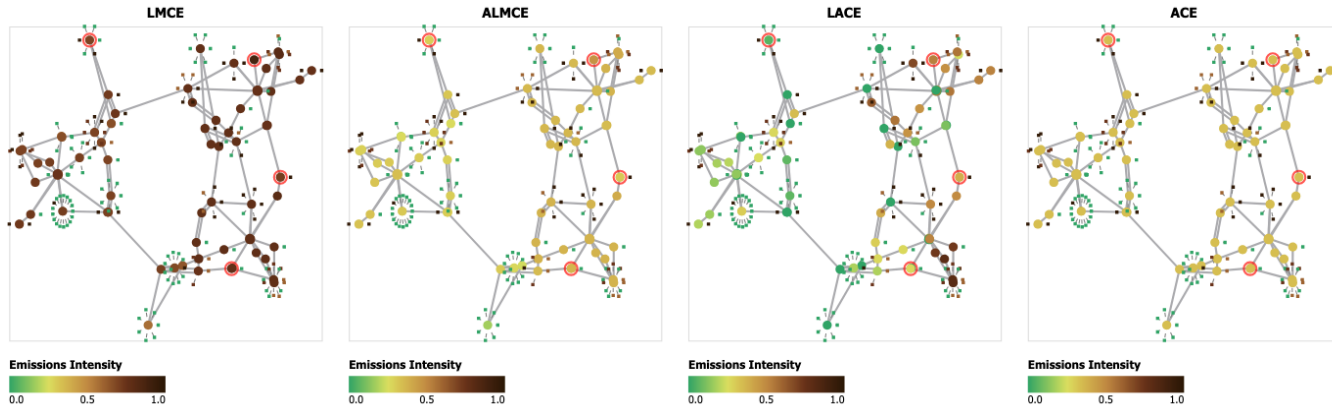
- An electrical consumer wants to reduce their carbon emissions, how should they shift their electrical consumption?
- What is the impact on total grid emissions vs. the 'accounted' emissions assigned to the consumer?

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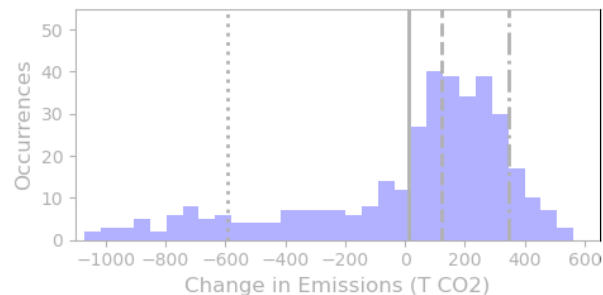
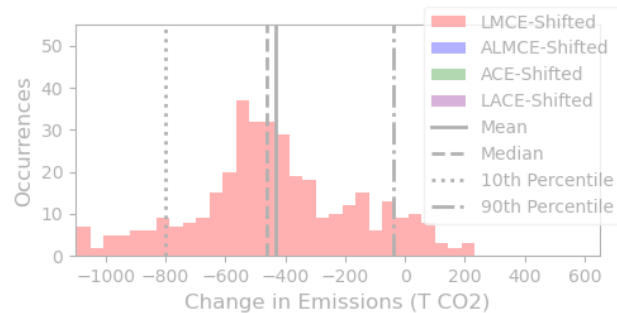
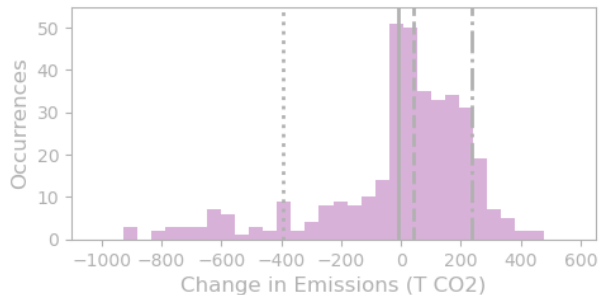
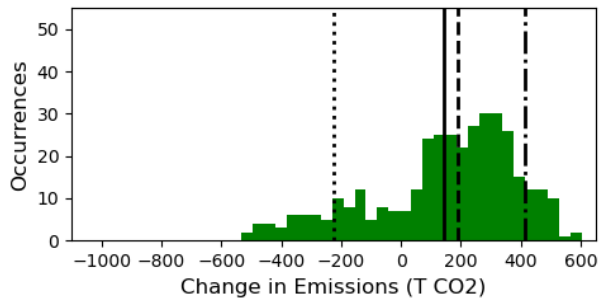
Datacenter User

- 1) Receives forecasted carbon metric data from the day-ahead power market
- 2) Change the schedule of some computation in time/location to increase/decrease electricity consumption
- 3) Evaluates the real-time carbon emissions



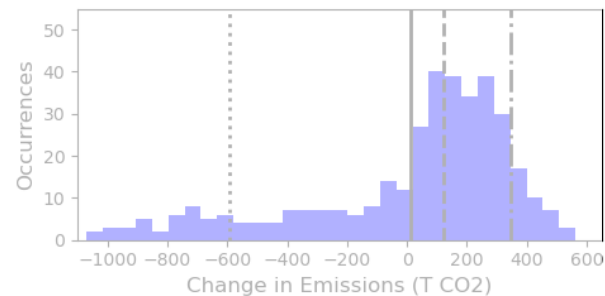
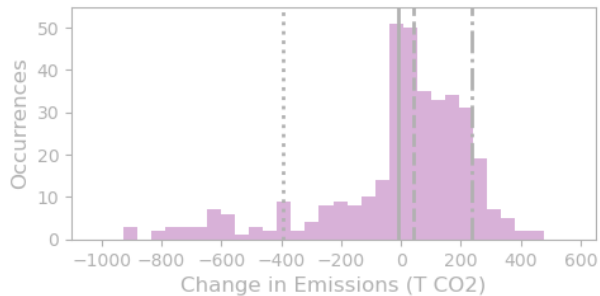
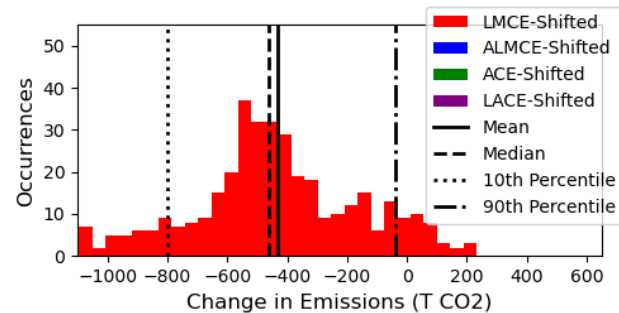
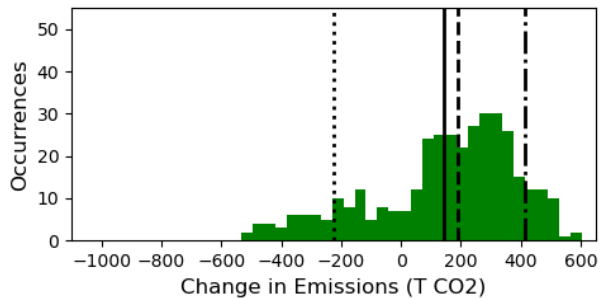
Following the metrics

- Following the metrics can increase total grid emissions



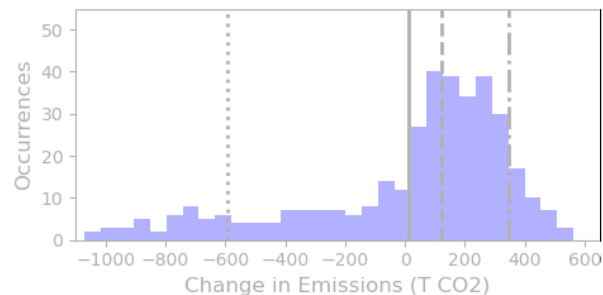
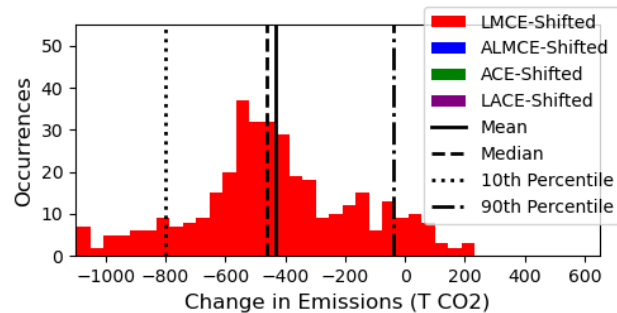
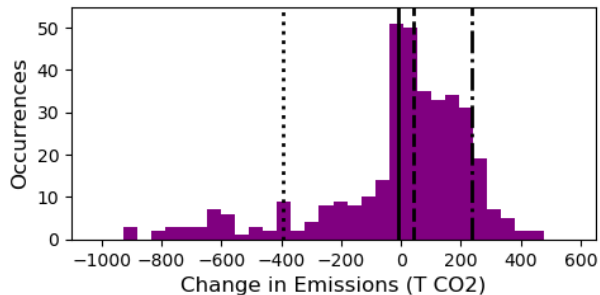
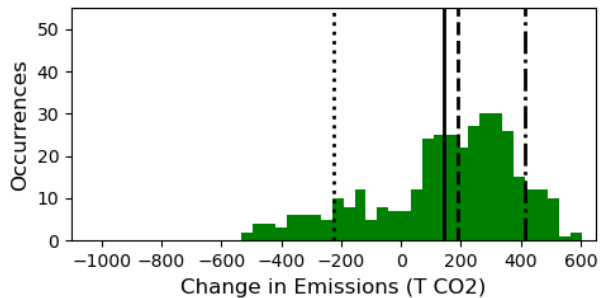
Following the metrics

- Following the metrics can increase total grid emissions



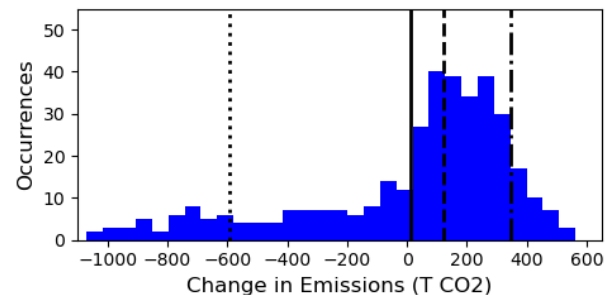
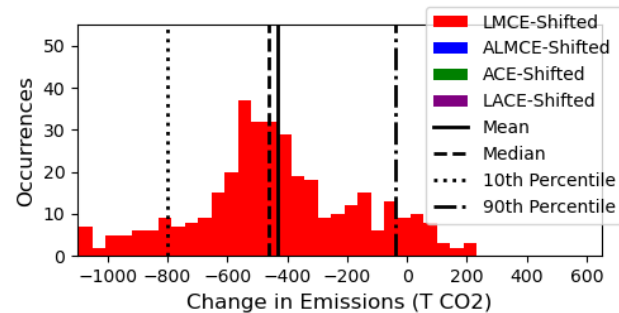
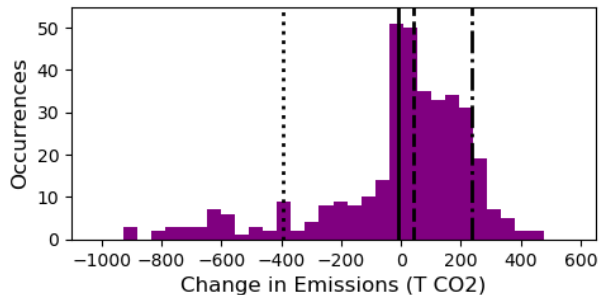
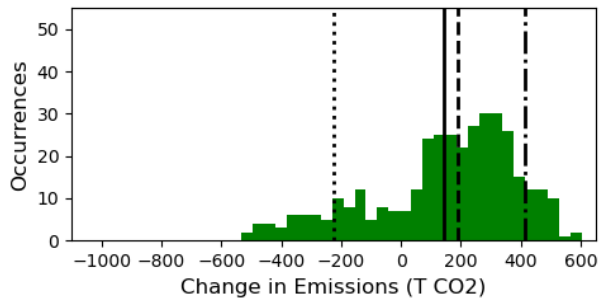
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System Emissions Impact

- Using LMCE, data-centers don't see as large of an improvement as expected
- Using ACE, data-centers reduce their emissions but increase total grid emissions

	Pre-Shift Accounted Emissions			Post-Shift Accounted Emissions (Estimated)		Post-Shift Accounted Emissions (Realized)		
	System	DC Loads	Non-DC Loads	DC Loads	System	DC Loads	Non-DC Loads	
LMCE	33.011	6.692	26.320	6.363 (-4.19%)	32.689 (-0.98%)	6.632 (-0.90%)	26.057 (-1.00%)	
ALMCE	15.828	3.161	12.666	2.865 (-9.36%)	15.833 (+0.03%)	3.015 (-4.62%)	12.818 (+1.20%)	
ACE	15.828	3.008	12.820	2.824 (-6.12%)	15.880 (+0.33%)	2.896 (-3.72%)	12.985 (+1.29%)	
LACE	15.828	2.707	13.121	2.370 (-12.45%)	15.825 (-0.02%)	2.595 (-4.14%)	13.230 (+0.83%)	

Table 3: Shifting Case Study: Emissions Results (Million Tons CO2)

Conclusion

- Different emissions intensity metrics can result in surprising changes to total grid emissions
- A 'good actor' following metrics for Scope 2 carbon accounting can increase total power grid emissions
- Results are unique to a specific network, generator fleet, and load shifting incentives
- Run ElectricityEmissions.jl on your own network data to see the possible impacts

References

- <https://github.com/WISPO-POP/ElectricityEmissions.jl>
- Gorka, J., Rhodes, N., & Roald, L. (2025, June). Electricityemissions. jl: A framework for the comparison of carbon intensity signals. In *Proceedings of the 16th ACM International Conference on Future and Sustainable Energy Systems* (pp. 19-30).