Reducing CO_2 Emissions With Virtual Transactions

A Bottom-up Simulation In MISO

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INVENIA LABS

Introduction - Invenia Labs

- *Virtual MWh participants* in US wholesale power markets
- Active in all Independent System Operators (ISOs) open to virtual transactions (representing ~⅔ of total US load)

- Research Team of ~30 people (Power Systems, Machine Learning, Data Science, Research Software Engineering)
    - https://www.invenia.ca/labs/

Introduction - Goal and Research Questions

Goal: Reduce emissions from electricity grids using virtual transactions.

Research questions:

1. How do virtual transactions currently impact emissions in MISO?
2. How much could virtual transactions *potentially* impact ISO emissions?
3. How can we design Agents which would most reduce ISO emissions?

Overview

1) Virtual Transactions & Emissions
2) Simulation Tool Overview
3) Experiments
4) Long Term Vision

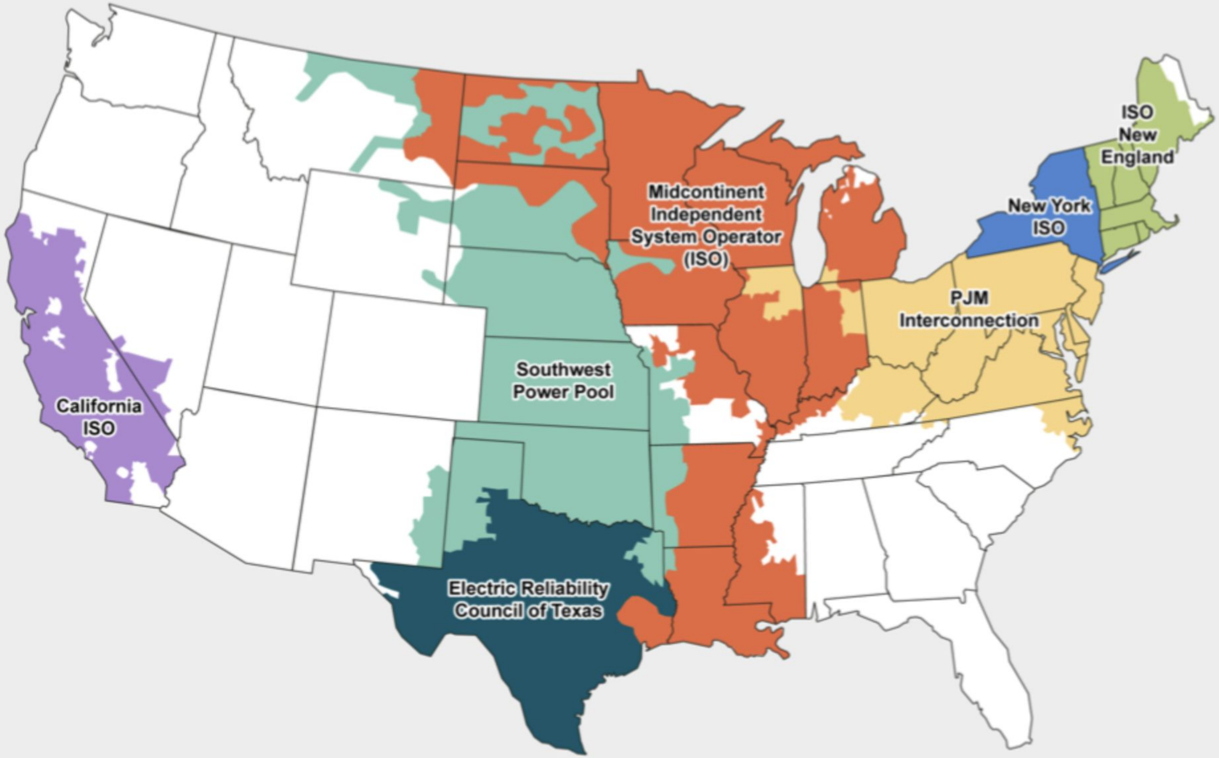
Virtual Transactions and Emissions

1) Virtual Transactions - Basics

- "Financial" product for increasing the efficiency and liquidity in the Day-Ahead (DA) wholesale market of US ISOs
- No physical obligation; awarded at Day-Ahead (DA) and settled at Real-Time (RT)
- Treated equally with physical generation and load in the DA unit commitment and economic dispatch
- Impact generator *unit commitments*
- Impact (directly) DA and (indirectly) RT Locational Marginal Prices (LMPs)
  - Incentives to converge prices!

*** See: Hogan, Virtual Bidding and Electricity Market Design, 2016**

1) Virtual Transactions - ISOs



1) Other key concepts

- **Unit commitment**
  - Key output of DA market clearing processes
  - Whether a generator will be scheduled to be on or off in Real Time

- **Emissions**
  - For simplicity, we focus on CO_2 from generators for now

- **Generator efficiency / capacity factor**
  - the share of a generators maximum that it is generating at
  - efficiency varies greatly by capacity factor in terms of energy output and emissions
  - ex: coal generator at 30% of its max emits far more *per MWh* than if generating at 80%

1) Virtual Transactions and Market Clearing

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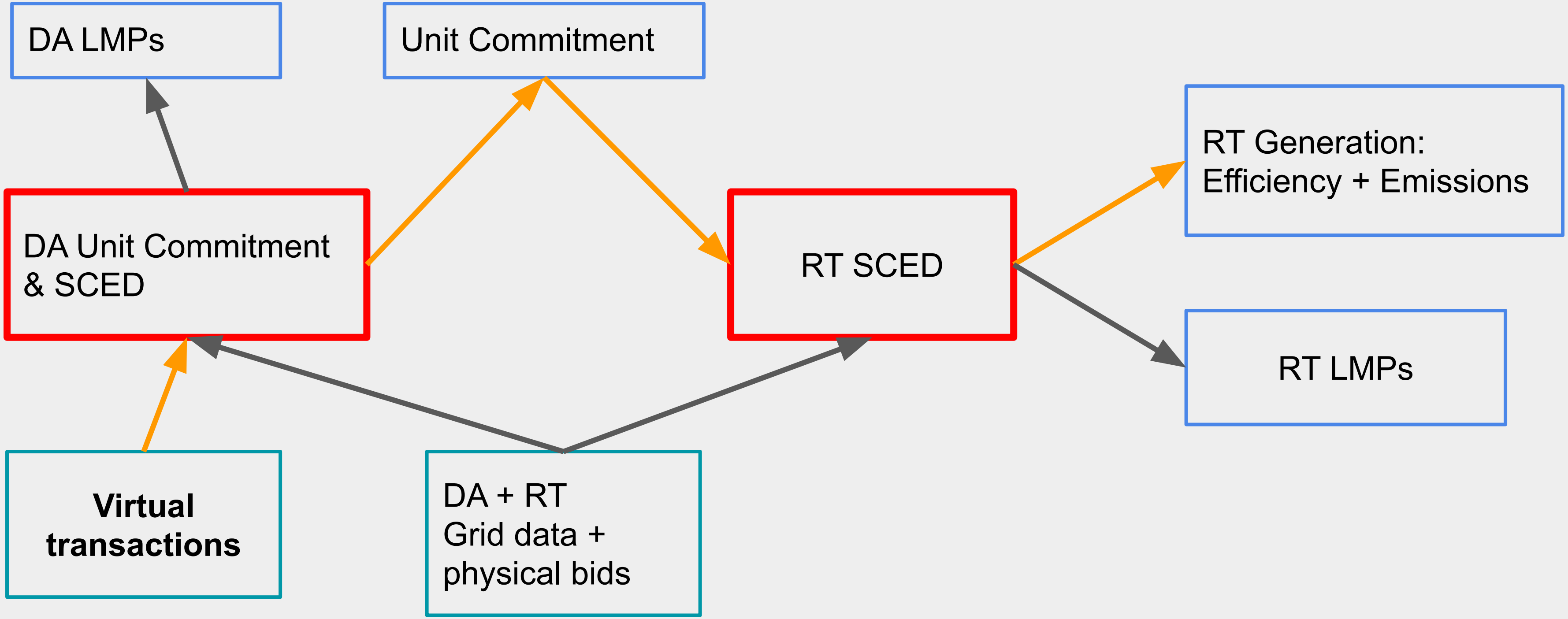


1) Virtual Transactions and Emissions - Literature

- *"the introduction of [virtual transactions] to California's wholesale electricity market resulted in [...] a 4.2% reduction in thermal energy per MWh,* ***implies a reduction in CO2 emissions of 145,000 tons****, focusing only on high demand hours."* , Wolak & Jha (2019)

- *"removing virtual transactions from the DAM had little impact on the DAM unit commitment outside of the fast-start CTs."*, Long & Giacomoni (2020)

Simulations Tool

2) Simulation Tool - Motivations

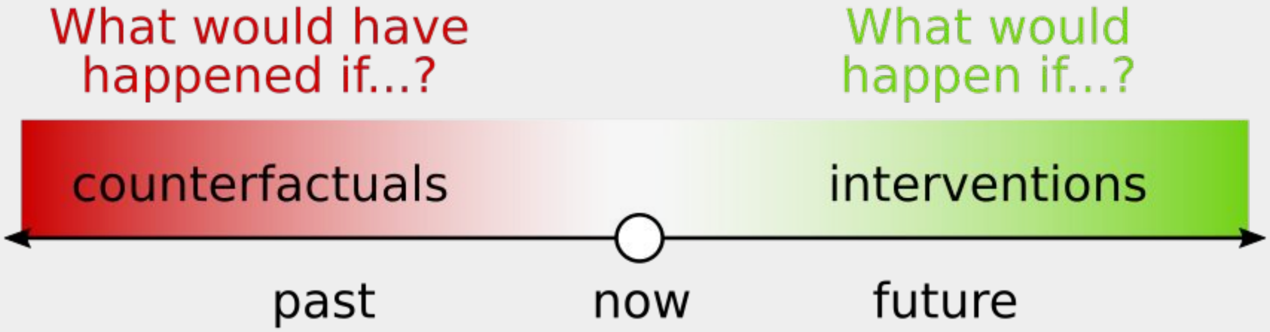
Goal: Develop Agents that generate virtual MWh which optimize an emissions objective, subject to *constraints*.

Key Issues

1) One history, limited data
2) Grid data is high dimensional
3) Non-Stationarity of inputs of market clearing
4) High causal density in input & output data
5) Properties of market clearing processes

2) Simulation Tool - Counterfactuals

- *"What would have happened if…"*
- Define "alternate reality" scenarios for simulations
  - Change real inputs from X to X'; observe change in outputs from Y to Y'
- **Claim:** Counterfactual simulations are <u>necessary</u> for developing Agents which lower emissions



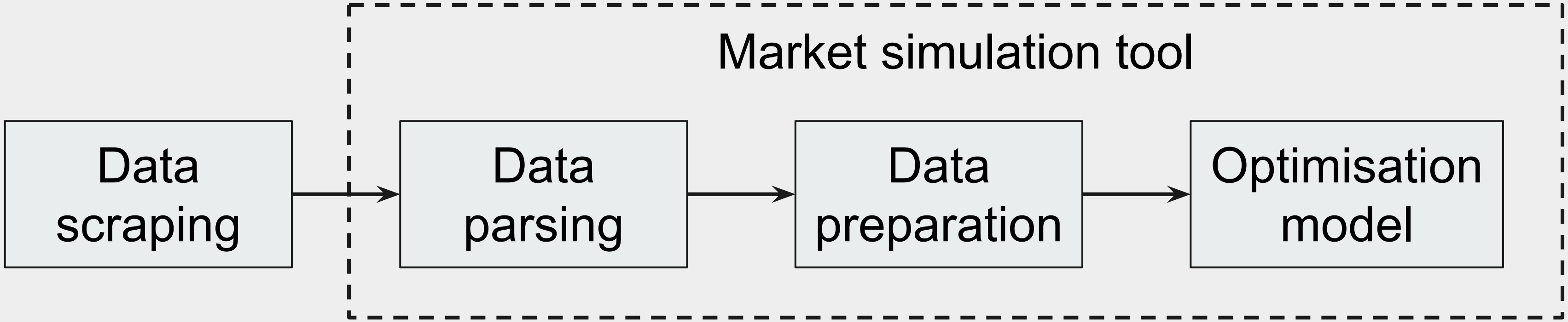
https://boxandarrowbrain.com/tag/causality

2) Simulation Tool - Key Features

1. Ability to run DA & RT unit commitment and SCED for MISO (currently)
2. Multi-day simulations, with two types of information flow across days
3. Ability to estimate CO_2 emissions produced from RT simulations
4. Ability to create counterfactual scenarios and run them
5. Automated data fetching and preparation from public and NDA data from ISO and other sources
6. Set of analysis & plotting tools
7. ISO-agnostic framework for everything

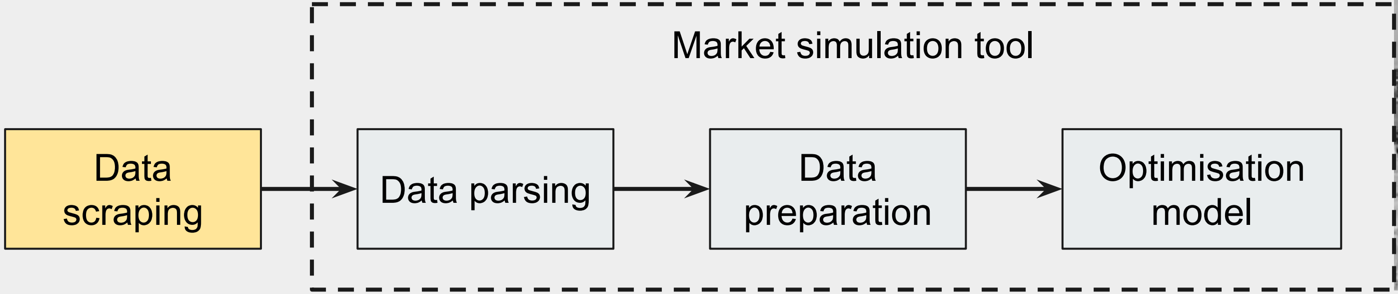
Currently: good accuracy on unit commitment, clearance, and MEC.

2) Simulation Tool - Basic Structure



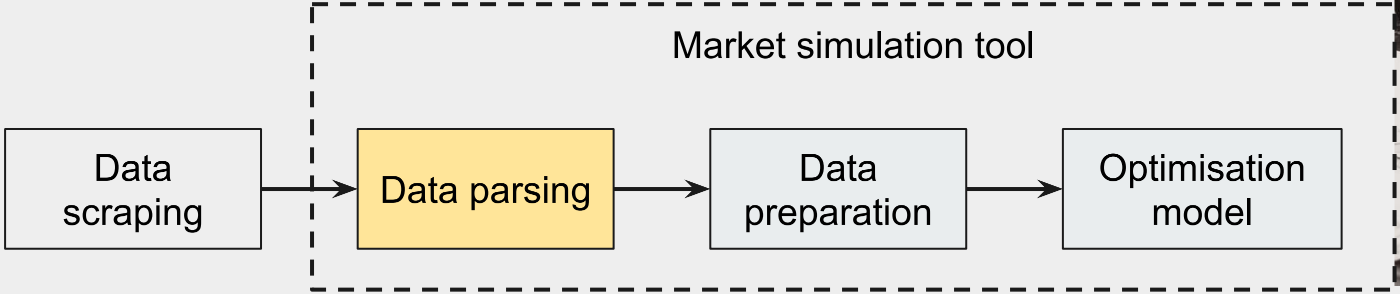
2) Simulation Tool - Data Scraping

- Retrievers scrape raw data from ISO, EIA, etc.
    - Grid topology, load patterns, generator properties, emissions data, etc.
- The main task here is archiving, not making sense of the data



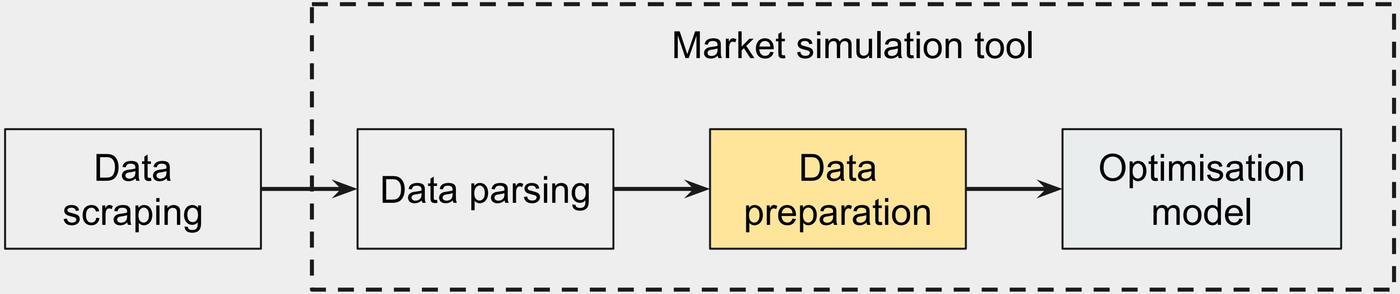
2) Simulation Tool - Data Parsing

- Opinionated parsers that interpret the raw data and return easy-to-use data structures
- Requires a lot of work from data scientists and researchers



2) Simulation Tool - Data Preparation

- Data is prepared into a form containing all required information to run the simulations
- Involves understanding the ISO's practices



2) Simulation Tool - Optimisation Model

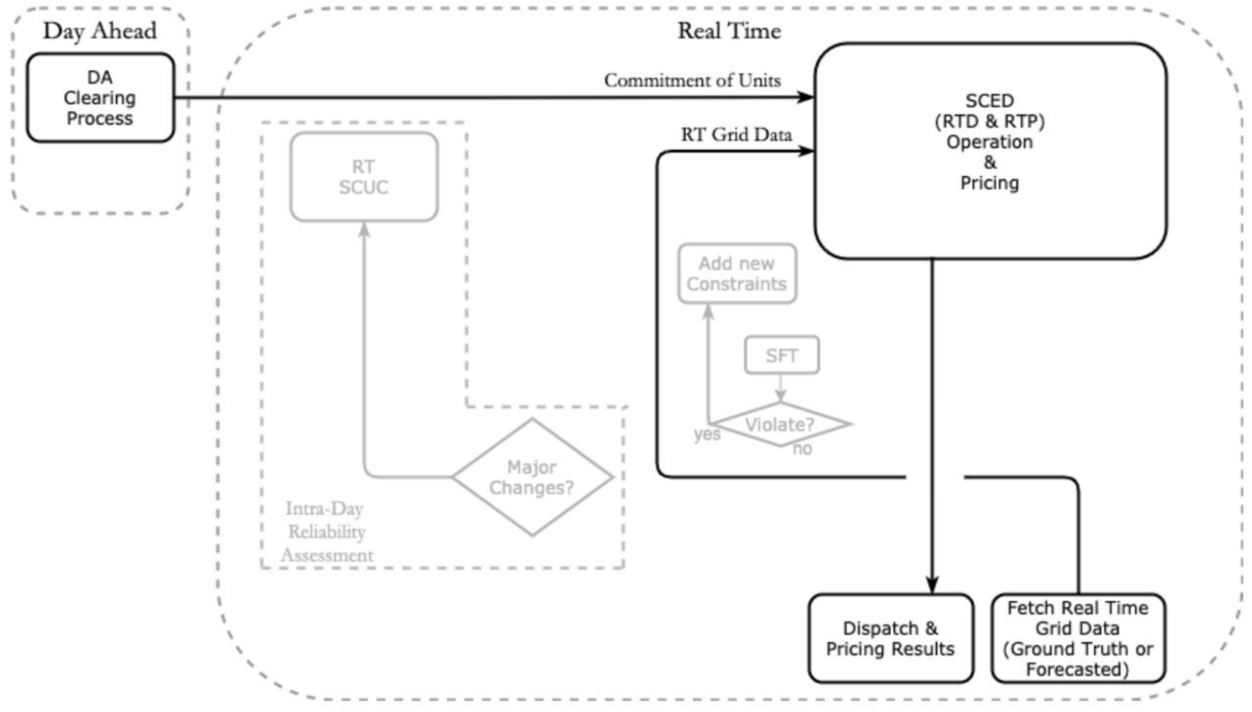


Fig. 5. Real Time Market Clearing & Operation Process in MISO (Invenia's current approximation)

2) Simulation Tool - Generator Emissions

Fuel Mix Average Method

Generation scaled by average emissions per MWh for each fuel type

- widely used method
- very simple and quick to apply
- <u>good results for historic emissions as long as sufficient aggregation</u>

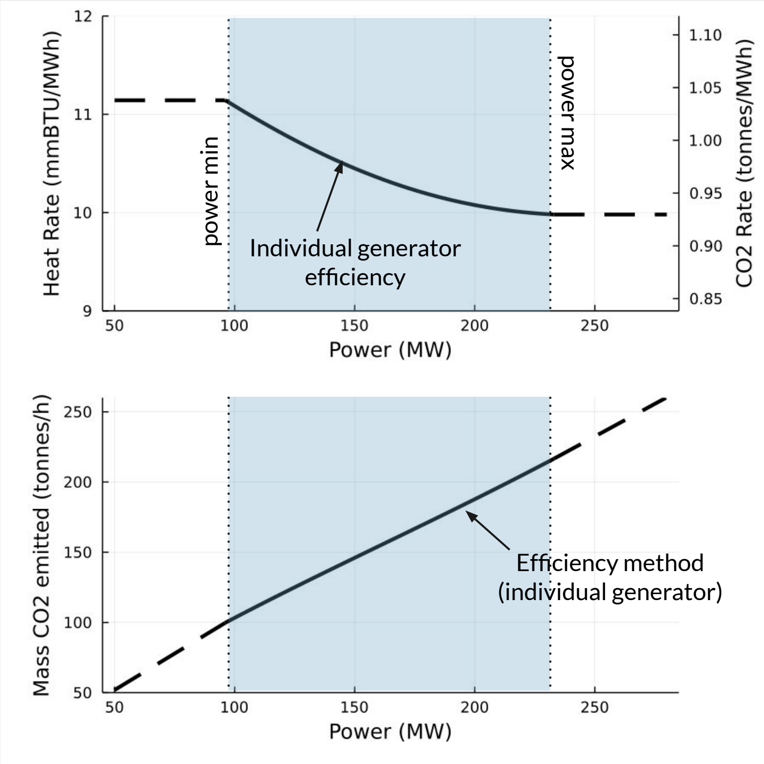
Generator Efficiency Method

Emissions vs generation curves for each generator, taking efficiency into account

- uses parameterised heat rate (efficiency) curves
- requires hard generator data wrangling
- <u>necessary if interested in accurate emissions for individual generators or counterfactuals</u>

2) Simulation Tool - Generator Emissions

Coal (EIA ID 1619_2)



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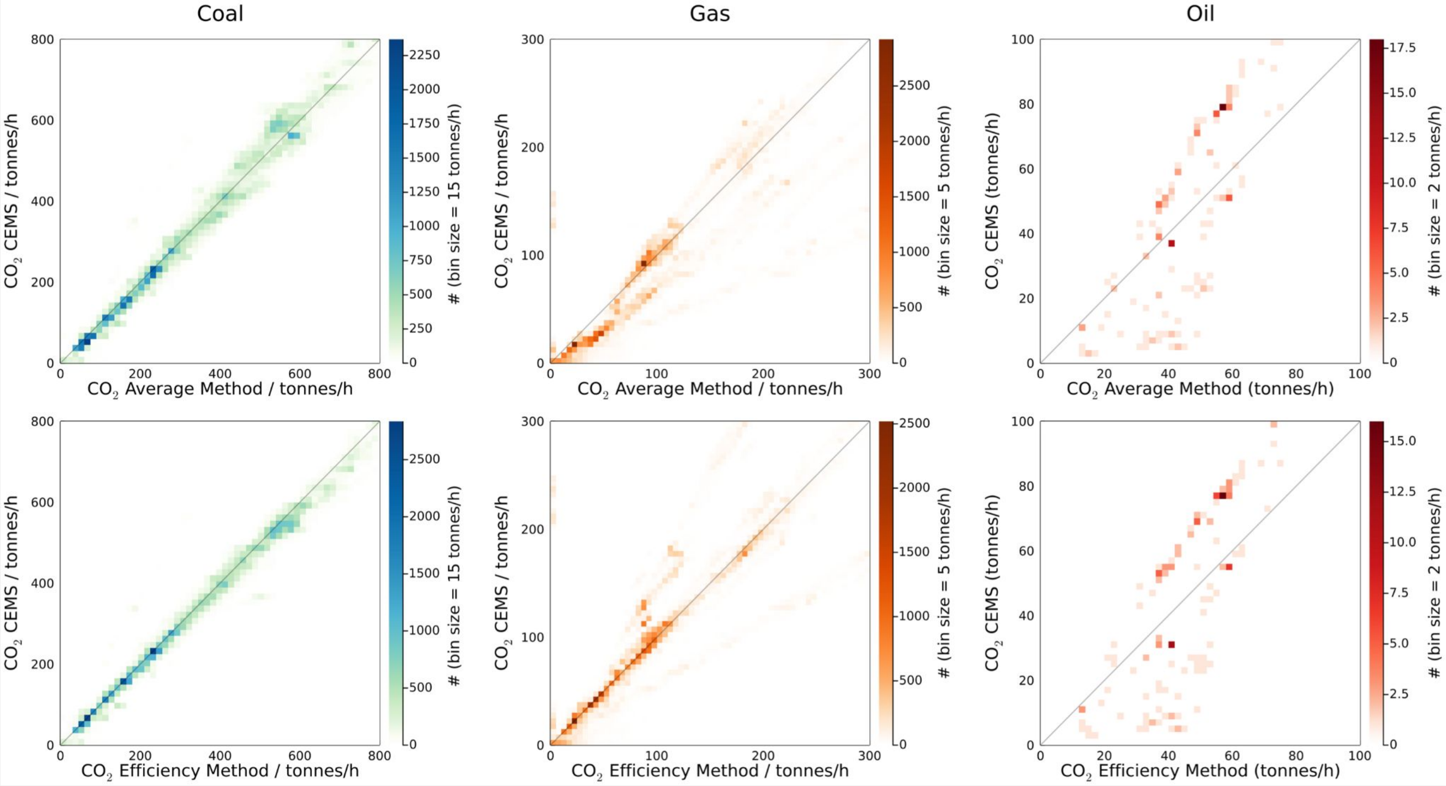


Experiments

3) Experiments - Methodology

- Simulate entire MISO grid; DA & RT market clearing processes
  - Solve DC OPF
- Mostly real data; some guesswork where real data unavailable
- Information sharing between
  - DA and RT and
  - Day T_n to Day T_{n+1}
- 49 simulation days (7 x 7-day periods); >300 simulations total

3) Experiments - What was Run

Simulations were run across the following scenarios:

1. Baseline (re-create reality)
2. Scale marketwide virtual transactions by 0x → 32x
3. Scale marketwide INC (virtual supply) by 0x → 8x
4. Scale marketwide DEC (virtual demand) by 0x → 8x

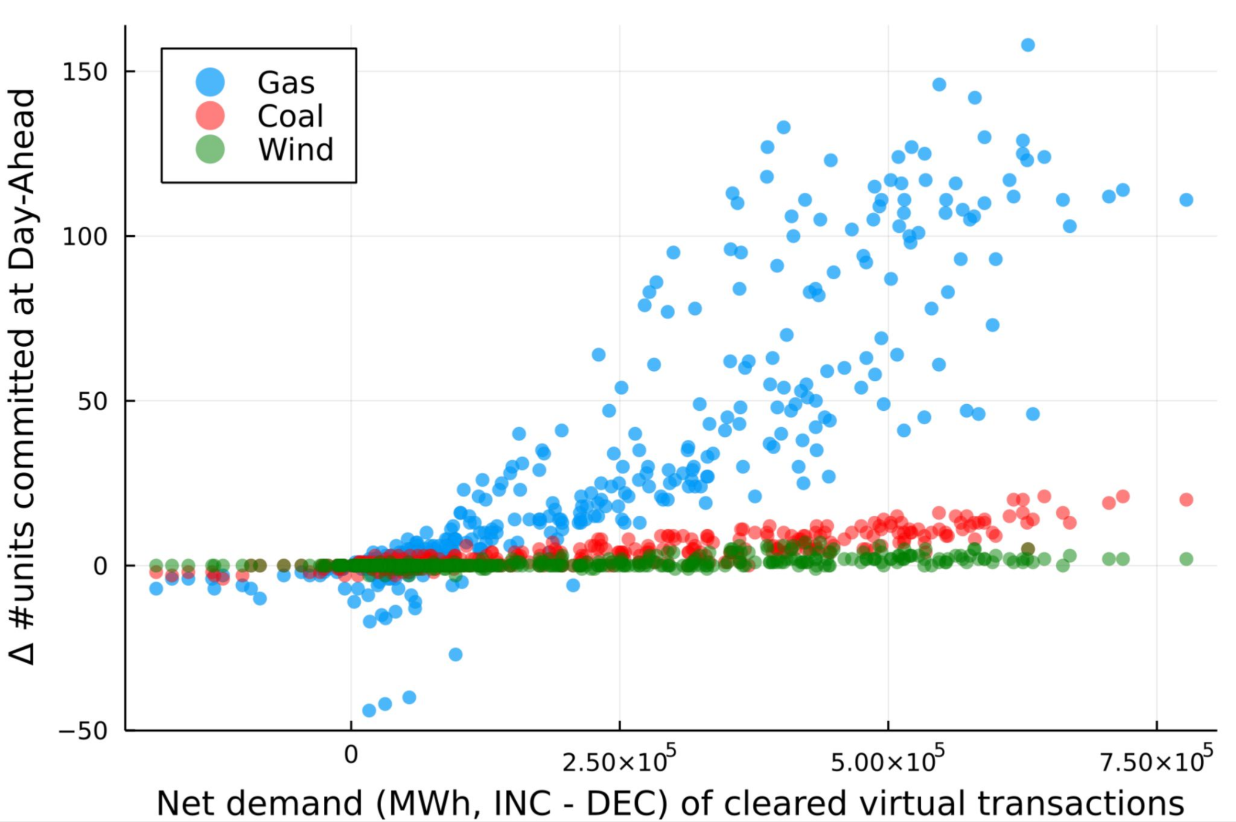
3) Experiments - Outputs Tracked

- Unit commitment count by generator type
- Grid fuel mix by generator type (MWh)
- Estimated total tonnes CO_2
- Generator efficiency (tonnes CO_2 / MWh)
- Net virtual transactions cleared (i.e. supply - demand)

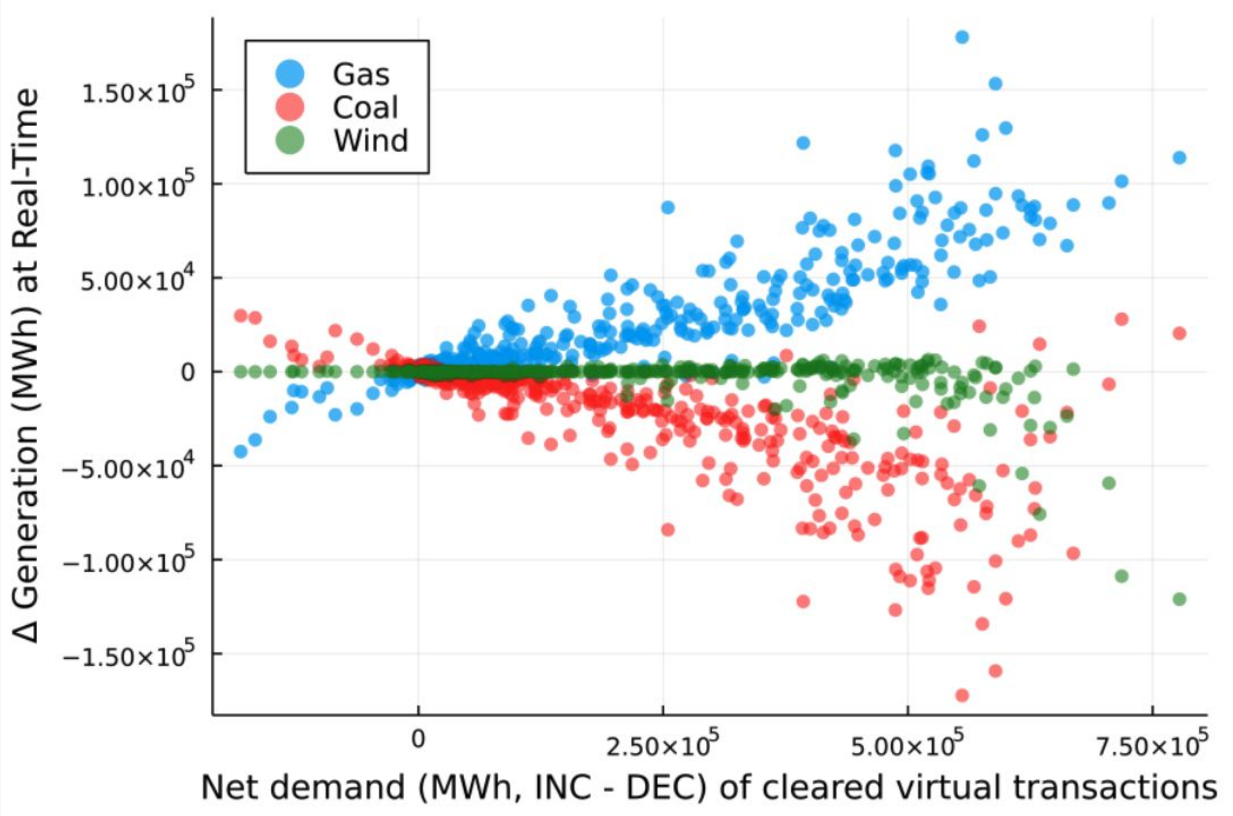
3) Results - First Order Impact - no Virtuals

	Relative change in MISO CO_2 emissions (%) (reality vs "no virtuals")
2017-2018	0.025% ± 0.009%
2018-2019	0.014% ± 0.009%
2019-2020	0.050% ± 0.011%
2020-2021	0.015% ± 0.011%
All	**0.026% ± 0.007%**

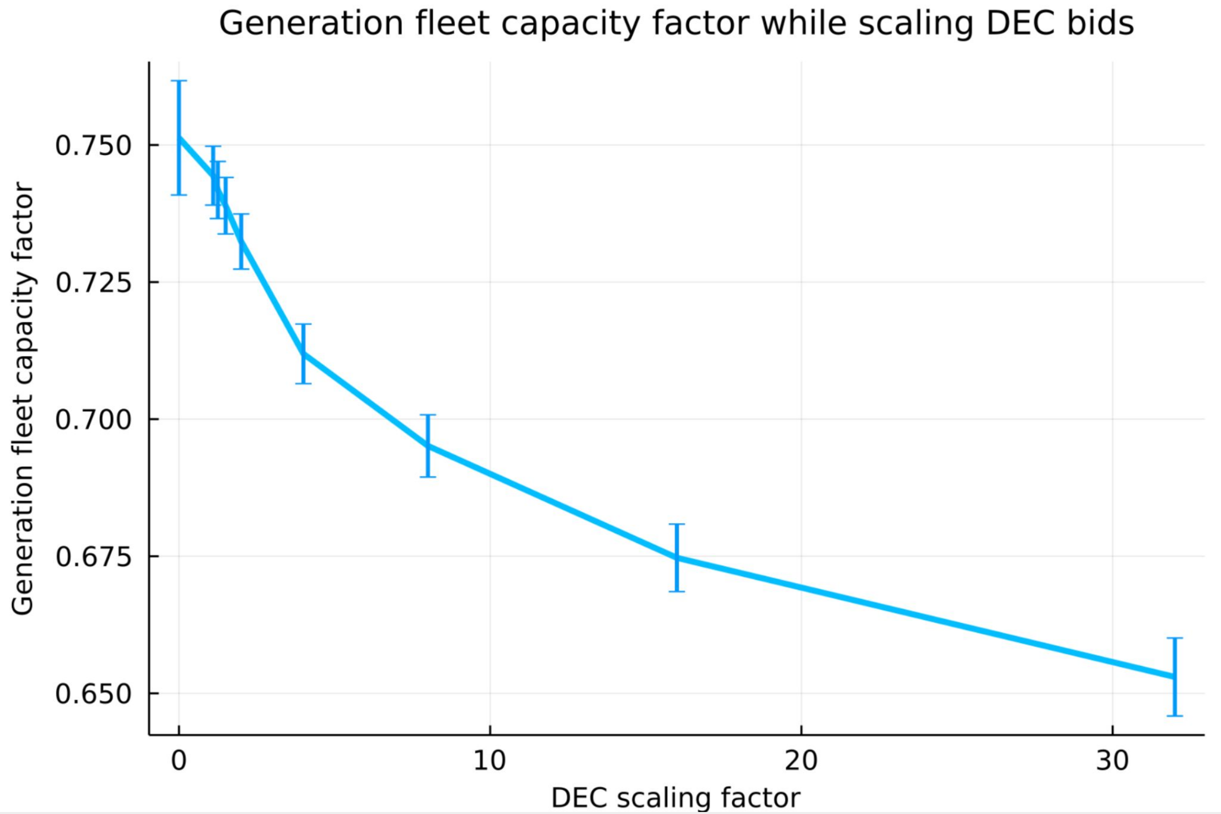
3) Results - Net Virtual Demand → More DA Gas



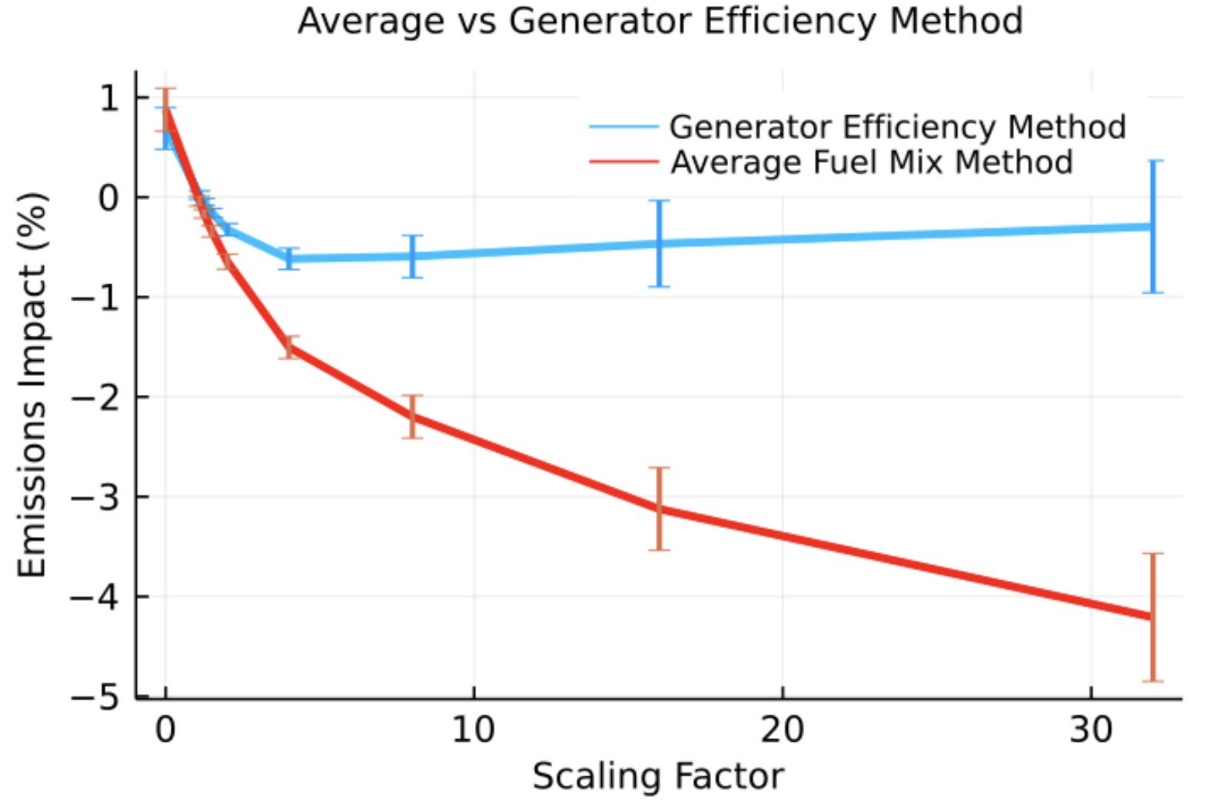
3) Results - Net Virtual Demand → Less RT Coal



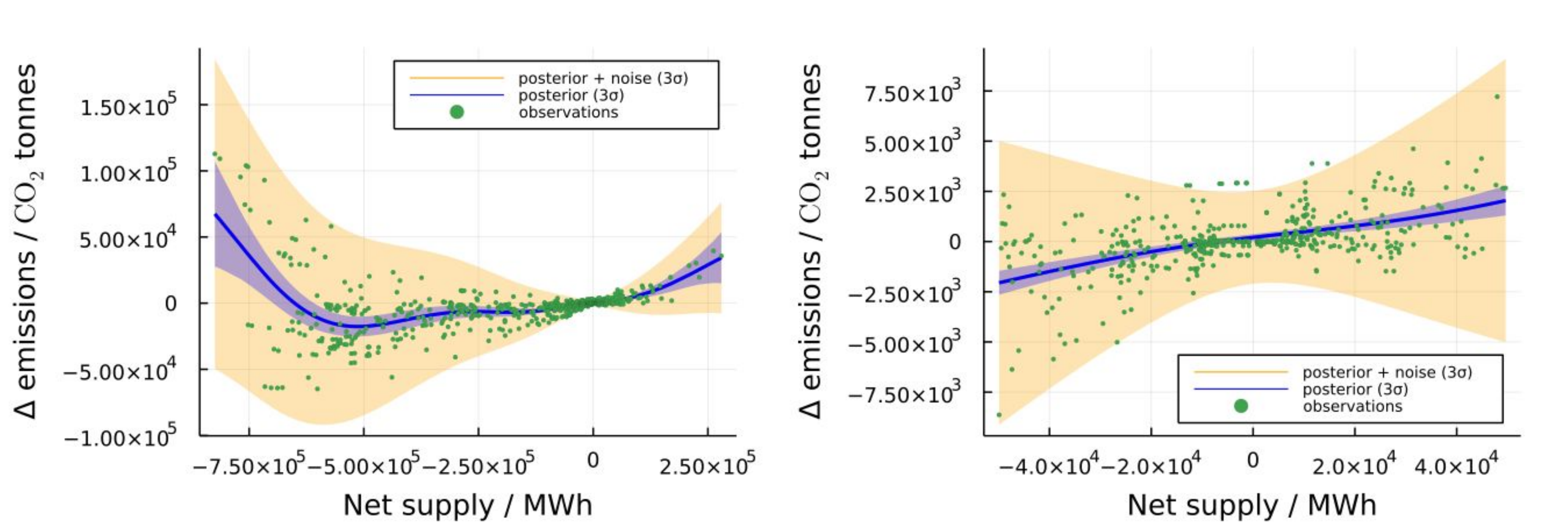
3) Results - Net Virtual Demand → Capacity Factor in RT



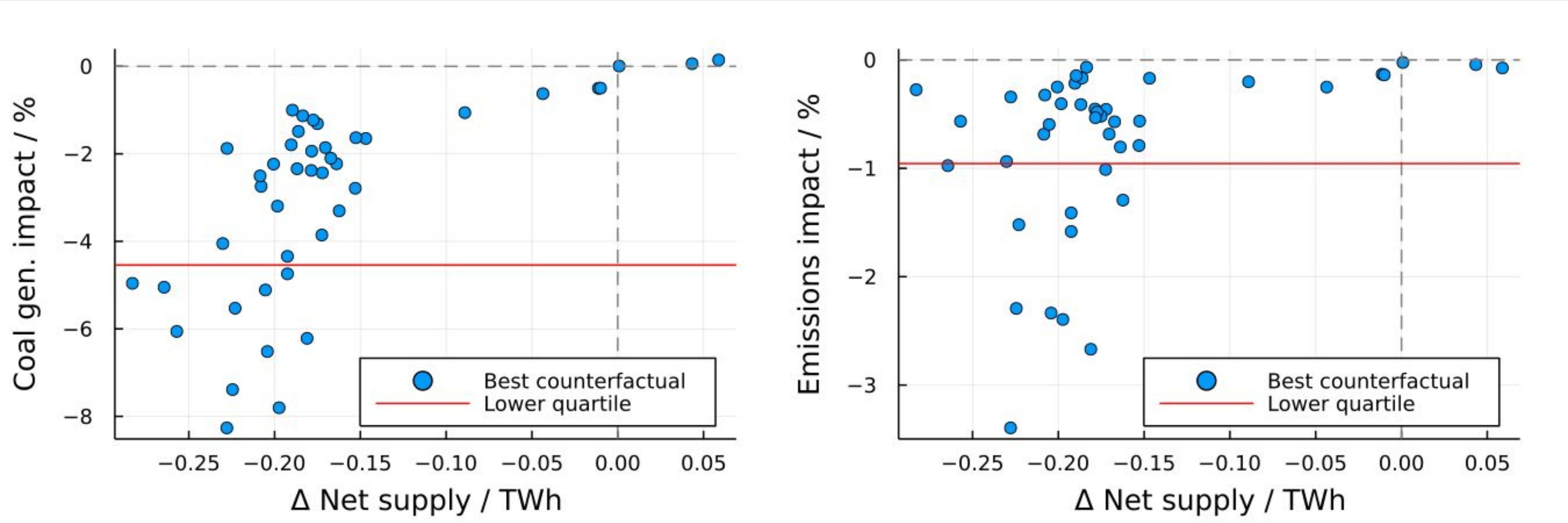
3) Results - Generator Efficiency



3) Results - Emissions Impact



3) Experiments - Results - Naive Ceiling Analysis



3) Experiments - Conclusions

1. Emissions impact limited to 1-3% from naive simulations

2. Net demand virtual transactions → “cleaner” fuel mix,
    a. **but** generator efficiency is a constraint on emissions impact

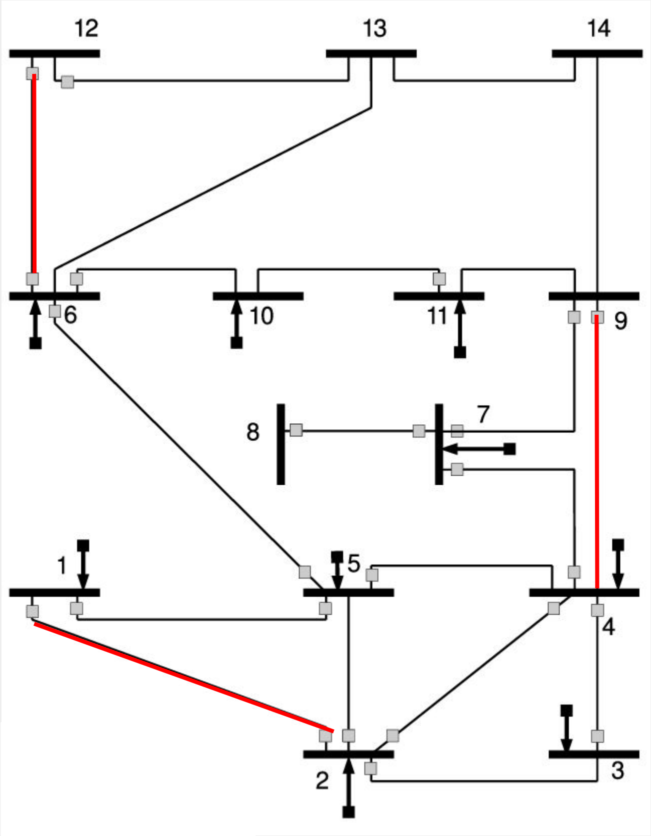
4) Market Simulations - Technical Challenges

The main challenges we face are from *incomplete availability of data* and understanding how to use it.

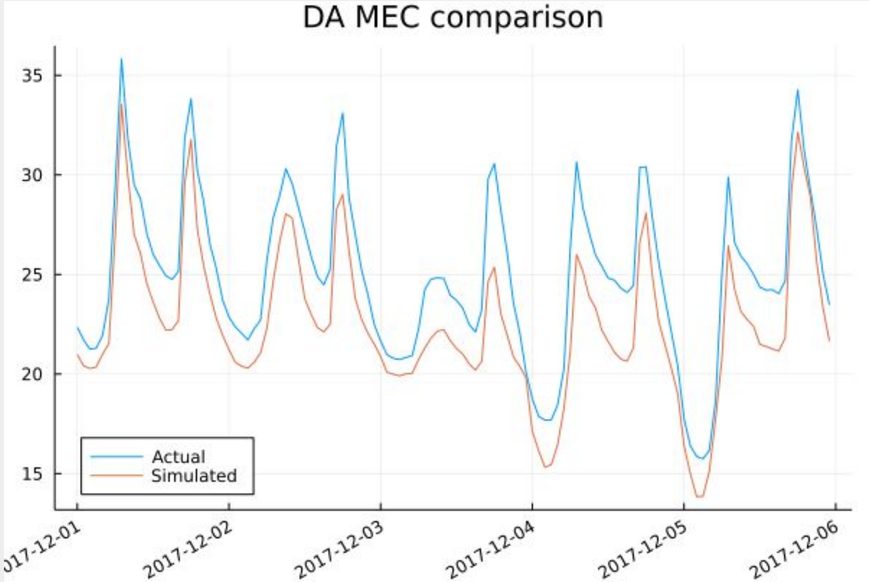
1. Bus Level & Congestion Modelling
2. Real-time load interpolation
3. Grid Connectivity
4. Scaling

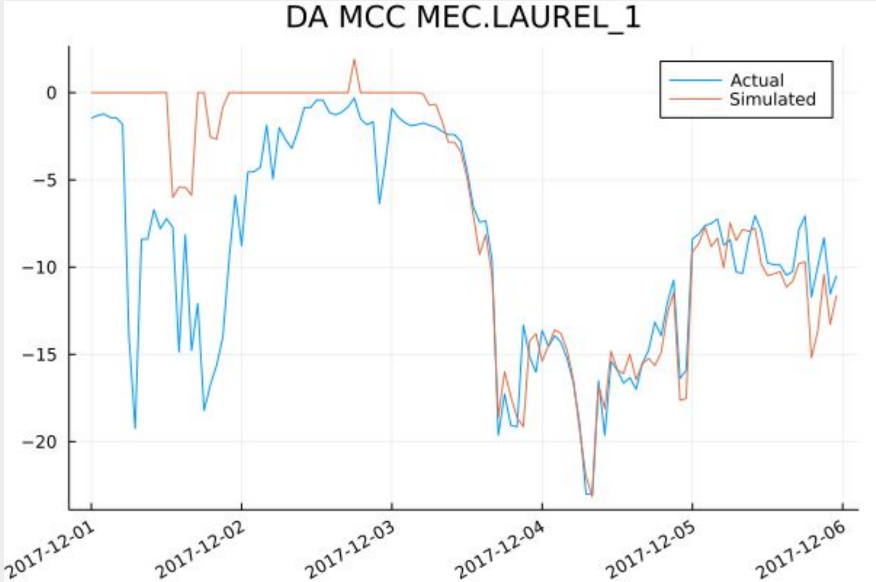
4) Technical Challenges - Bus Level Modelling

- Only a small subset of branch constraints are enforced by the ISO (*monitored lines*).
  - We don't know these in advance.
- Can use historical binding constraint data to select which constraints to enforce.
  - ⇒ Easy to miss congestion that is flowing in *unmonitored lines*.



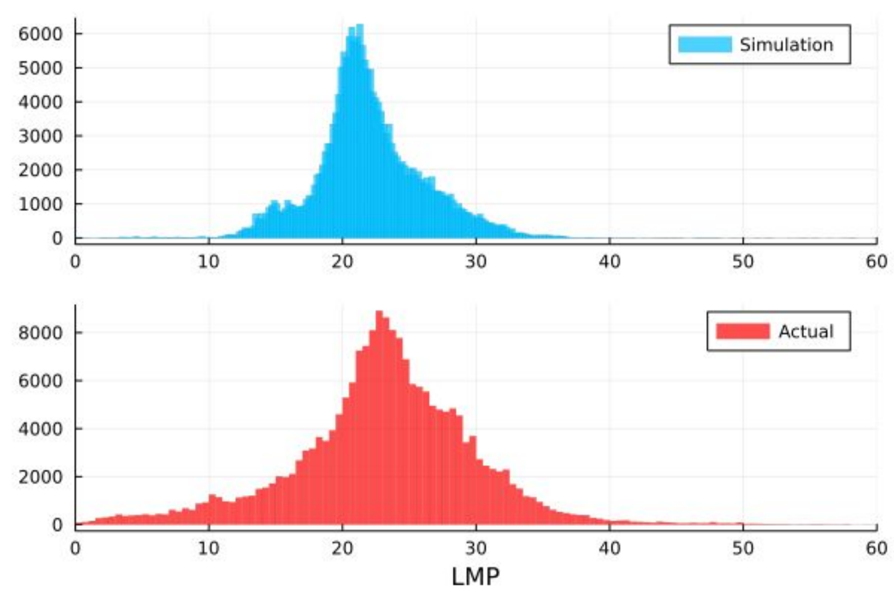
4) Technical Challenges - Congestion Modelling



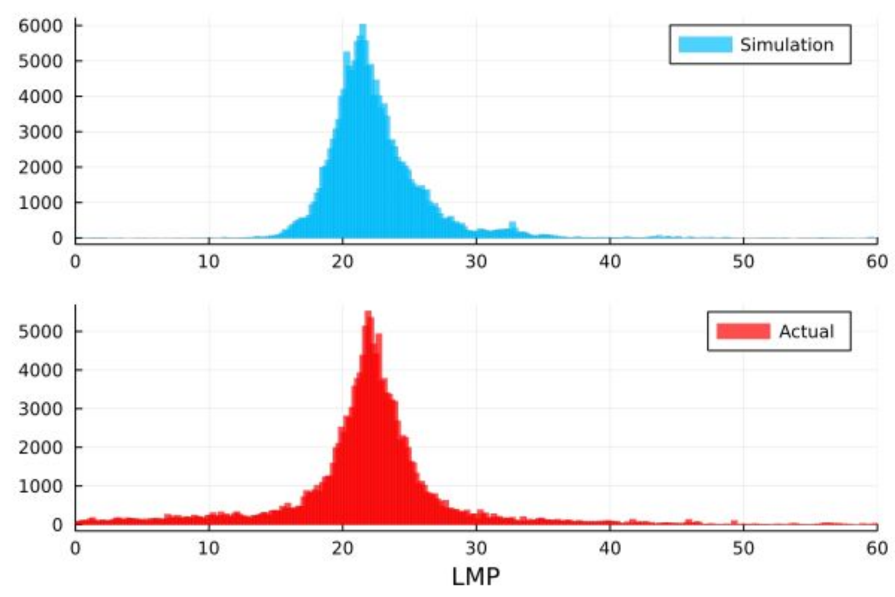


4) Technical Challenges - Congestion Modelling

DA



RT

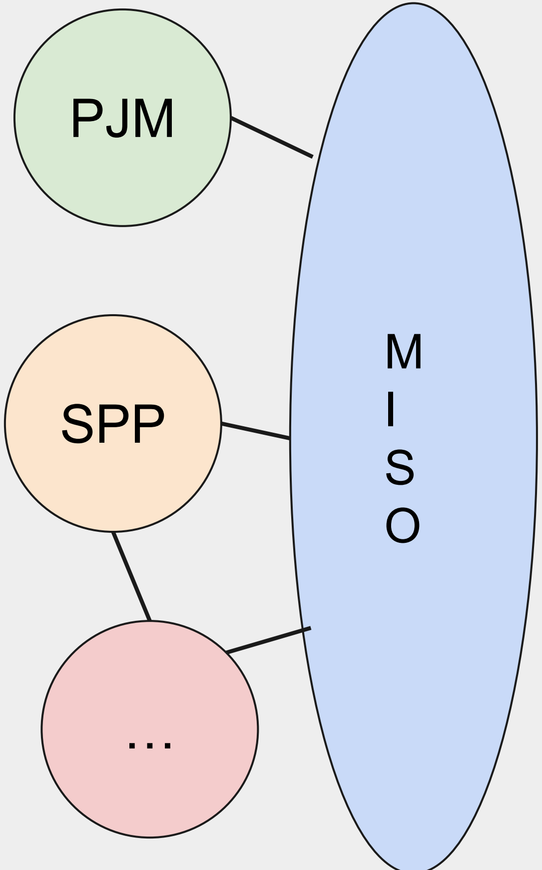


4) Technical Challenges - Load Interpolation

- In DA, load data is hourly resolution.
- In RT, we don't have actual hourly loads or short-term load forecasts.
  - *State Estimator Models*, are published 4 times a day.
  - ⇒ only have 4 observations of RT load per day.
- We use an *interpolation technique* to obtain hourly values for the load at every bus,
  - ⇒ Big source of inaccuracy in the simulations.

4) Technical Challenges - Grid Connectivity

- MISO is strongly connected to other grids.
- Currently not considering bid data from external areas.
- We aggregate the external areas with a single "border bus" per neighbouring balancing authority.
  - We have verified that this impacts the shift factors, reducing our accuracy ceiling by ~20%.



4) Technical Challenges - Scaling Simulations

- We want statistically significant conclusions.
  - ⇒ running many simulations.
- Simulations are computationally expensive (large-scale security-constrained unit commitment)
- Dependency on commercial solvers makes it hard to run multiple in parallel.

4) Long Term Vision

1. Extend simulation accuracy and capacity to additional ISOs
   a. Ongoing now!

2. Design & use emissions-reducing agents
   a. Must satisfy market constraints/regulations (ex: must converge DA and RT prices)

3. Improve sophistication of emission-reduction strategies:
   a. *Ex: Forecast marketwide merit order & target coal → gas displacement specifically*
   b. Ex: Identify gas and coal generators that were “close to commitment” based on bid curves, must-run status and nodal LMPs
   c. Ex: reduce curtailment of renewable energy

4) Long Term Vision - Emissions-reducing Agents

<u>Offline</u> uses of Market Simulations

- *Insights* into grid/market behaviours and *inspiration* for Agent design
- Synthetic generation of realistic training data for forecasting models (i.e. addressing the "one history problem")

<u>Online</u> use of Market Simulations

- Forecast market inputs and simulate the market clearing process to get estimated emissions, conditional on our virtual MWh

4) Long Term Vision - Offline Use

observables : o

decisions : d - virtual MWh

Emissions : $E(d\,;\,o)$

$$\boxed{\text{World}} \xrightarrow{\;o\;} \boxed{\text{Emissions Estimator}} \longrightarrow E(d\,;\,o)$$

4) Long Term Vision - Live Agents

observables : o

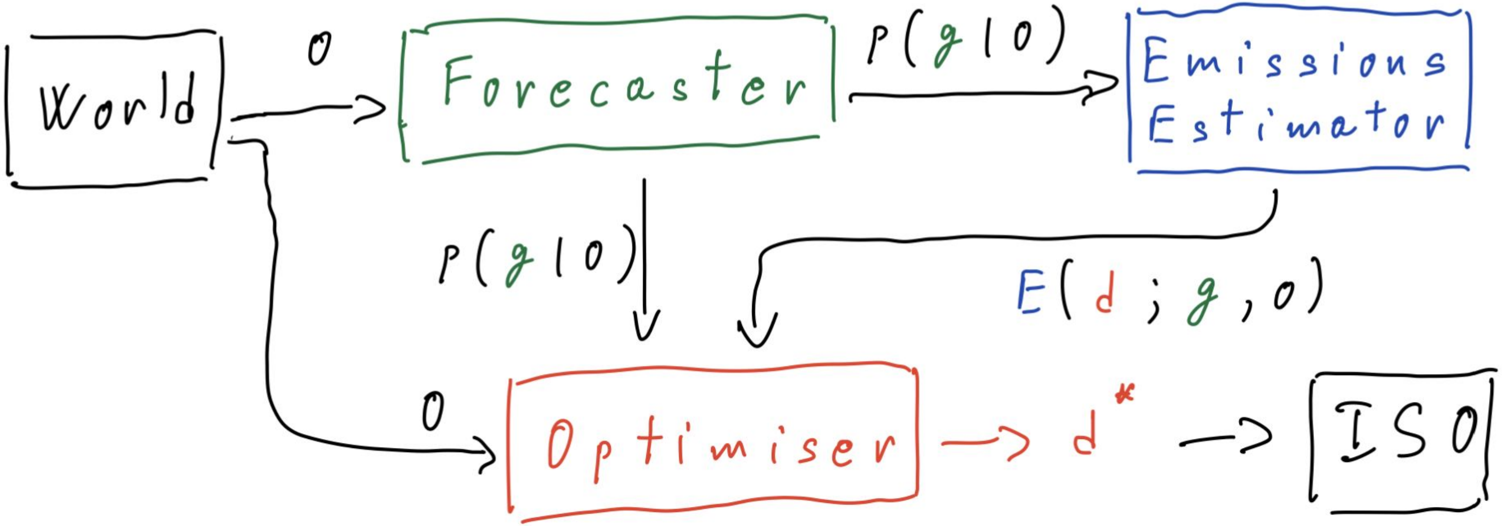
forecasts : $p(g|o)$

decisions : d - virtual MWh

Emissions : $E(d; g, o)$

Objective : $\mathcal{L}(E(d; g, o); \ldots)$

4) Long Term Vision - Live Agents



$$d^* = \underset{d}{\arg\min} \int \mathcal{L}(E(d; g, o); \ldots)\, p(g|o)\, dg$$

Summary

Goal: Reduce emissions from electricity grids using virtual transactions.

Built a market simulation tool for MISO

- Currently reasonably accurate, can run counterfactuals, and estimate historical emissions.

Virtual transactions impact on emissions in MISO?

- Limited to 1-3% from naive simulations.
- Net demand virtual transactions → "cleaner" fuel mix, but generator efficiency is a constraint on emissions impact.

Long term Vision: Agents which take in data and forecasts, and generate virtual MWh which optimize an emissions objective, subject to constraints.

Acknowledgements

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- Nicholas Robinson
- Raphael Saavedra
- Chris Davis
- Branwen Snelling
- Abraham Alvarez Bustos
- Andrew Rosemberg

Some of our other work:

https://invenia.github.io/blog/

We're very open to collaborations and are also hiring!