Carbon Accounting Paradigms:
Benefits and Limitations

Noman Bashir, Abel Souza, David Irwin, Prashant Shenoy - University of Massachusetts Amherst
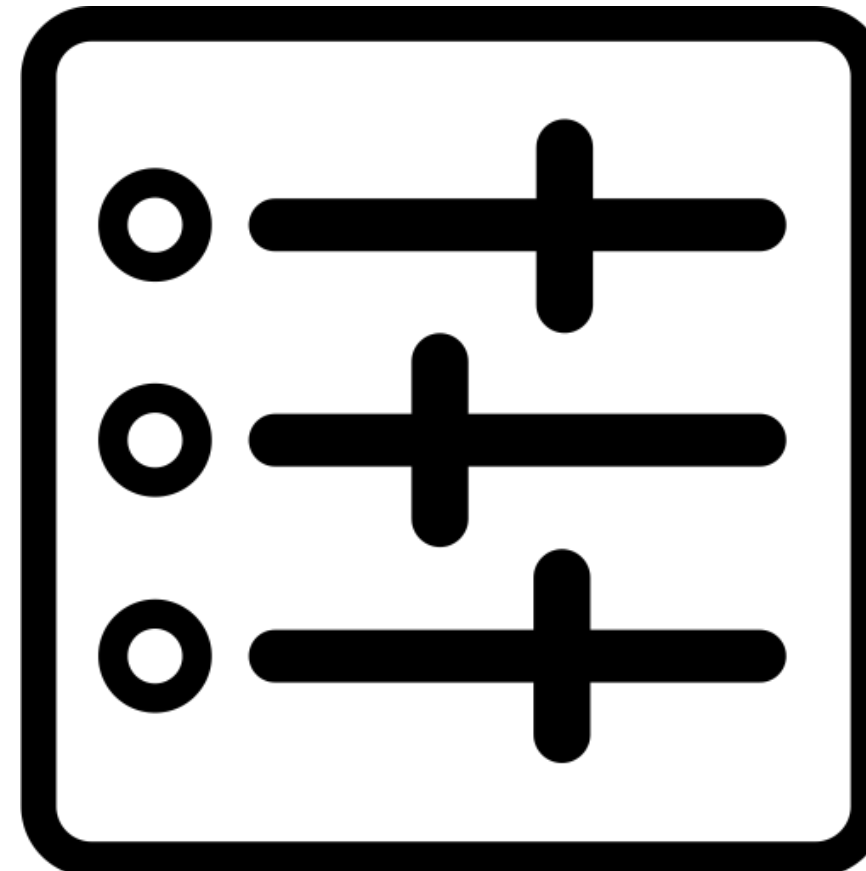nbashir@umass.edu
02/25/2023
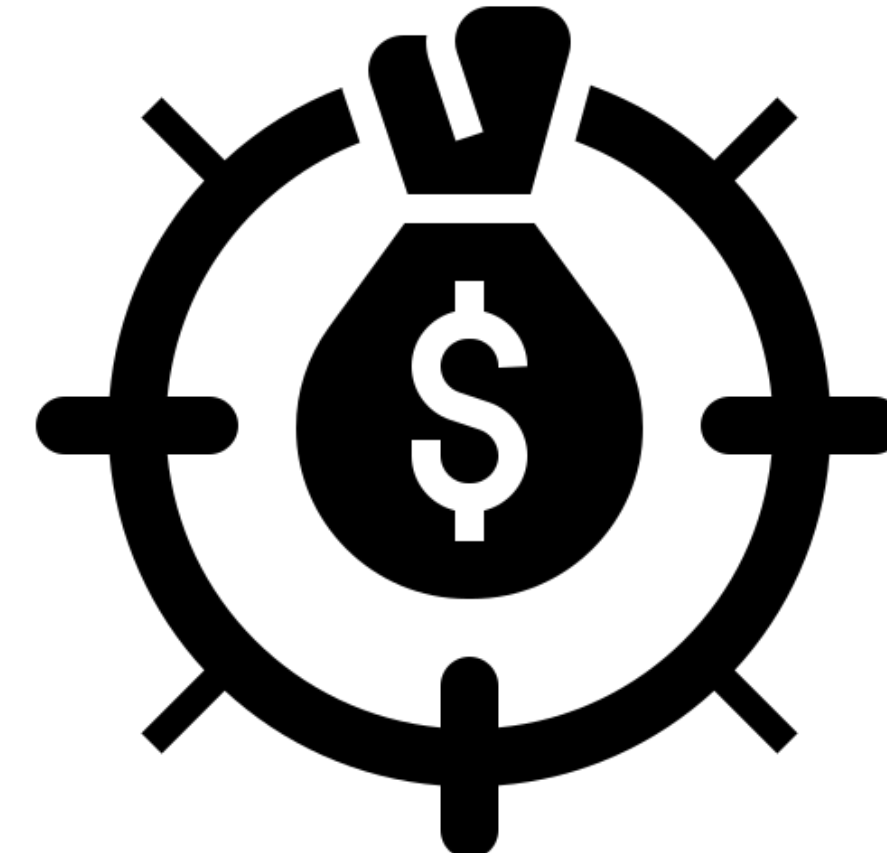
Ingredients for Sustainable Computing

Visibility	Control	Incentives

Visibility
- Embodied Carbon vs Operational Carbon
- Average & Marginal

Control
- Spatial Migration
- Delay Tolerance
- Suspend & Resume

Incentives
- Public Image / Optics
- Regulatory Pressure
- Carbon Tax or Penalty

Ingredients for Sustainable Computing
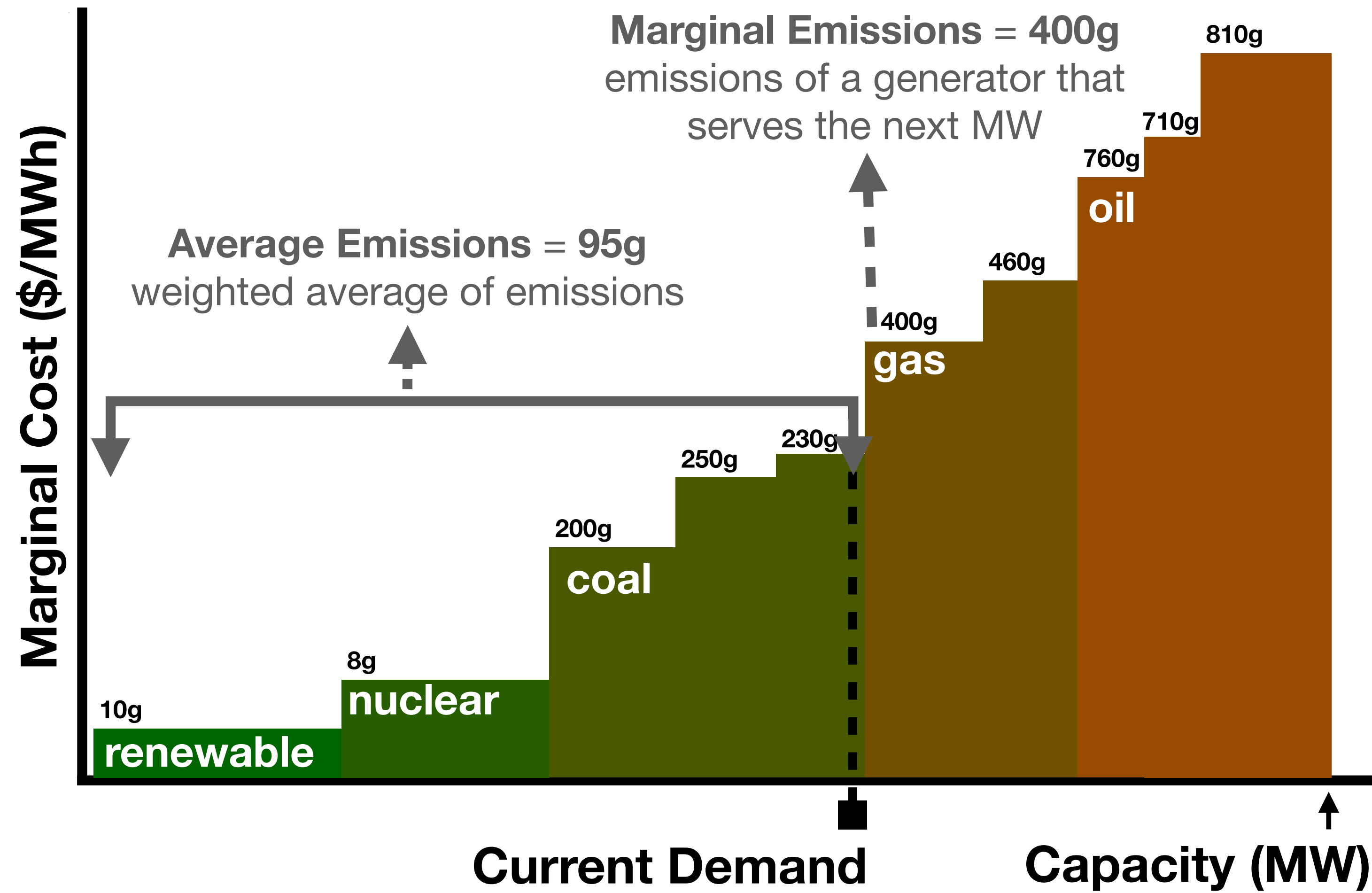
Visibility

- Embodied Carbon vs **Operational Carbon**

- **Average & Marginal**

Signal: What is best for the grid in short-term and/or long-term? It could be completely manufactured/fake.

Accounting: How much I have actually emitted or will emit? It should be highly accurate.

Average and Marginal Carbon Emissions

Marginal Emissions = **400g**
emissions of a generator that
serves the next MW

Average Emissions = **95g**
weighted average of emissions

Marginal Cost ($/MWh)

810g

760g
710g

oil

460g

400g

gas

250g   230g

200g

coal

8g
nuclear

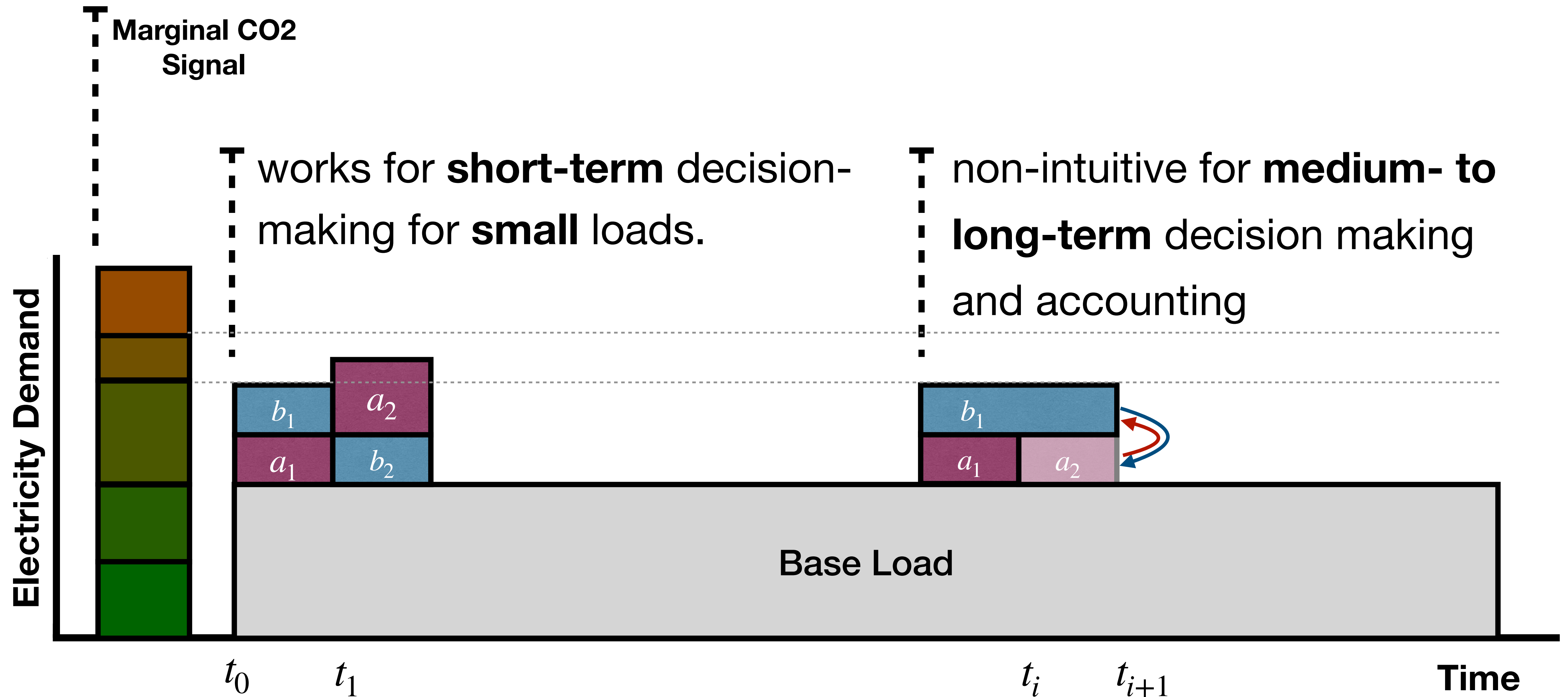10g
renewable

Current Demand

Capacity (MW)

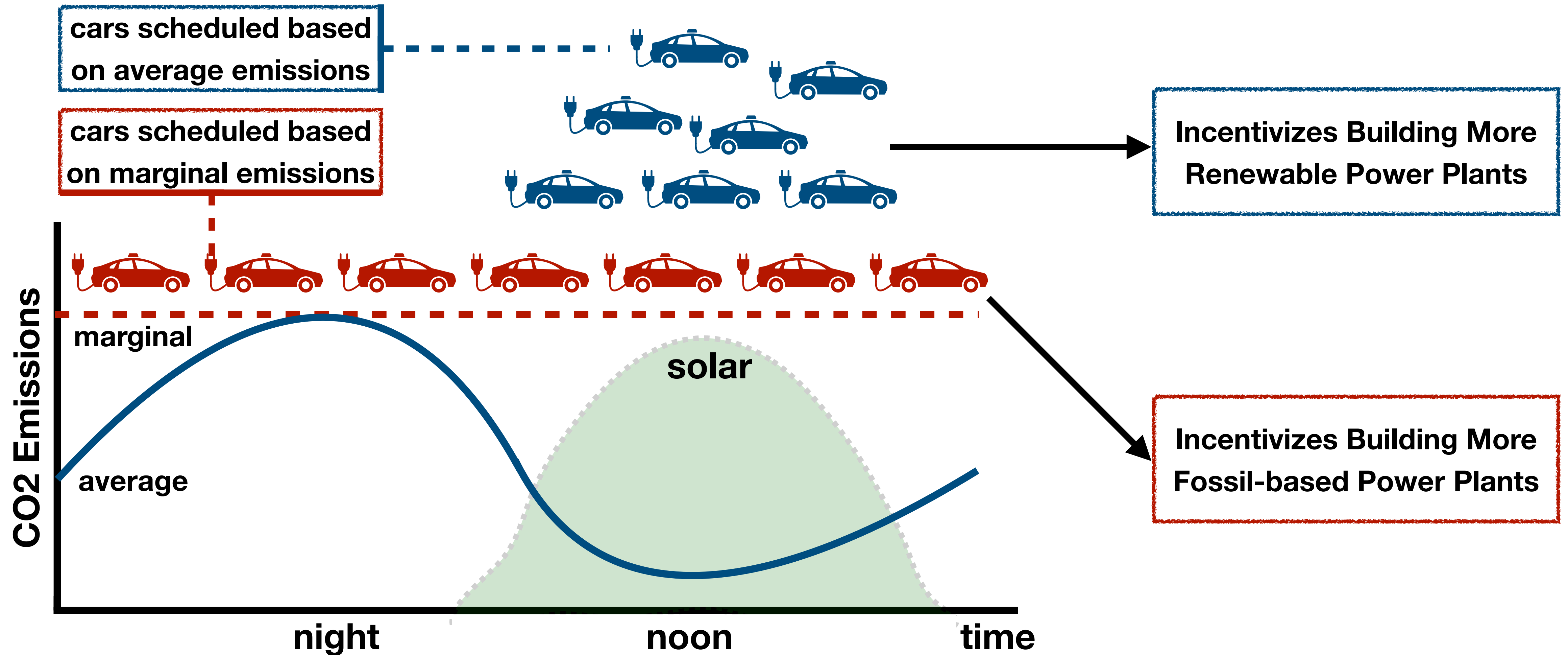**Average amortizes the emissions
over entire demand.**

versus

**Marginal signals the emissions
of the next generator.**

Marginal **seems** to be signaling
the actual carbon emissions as a
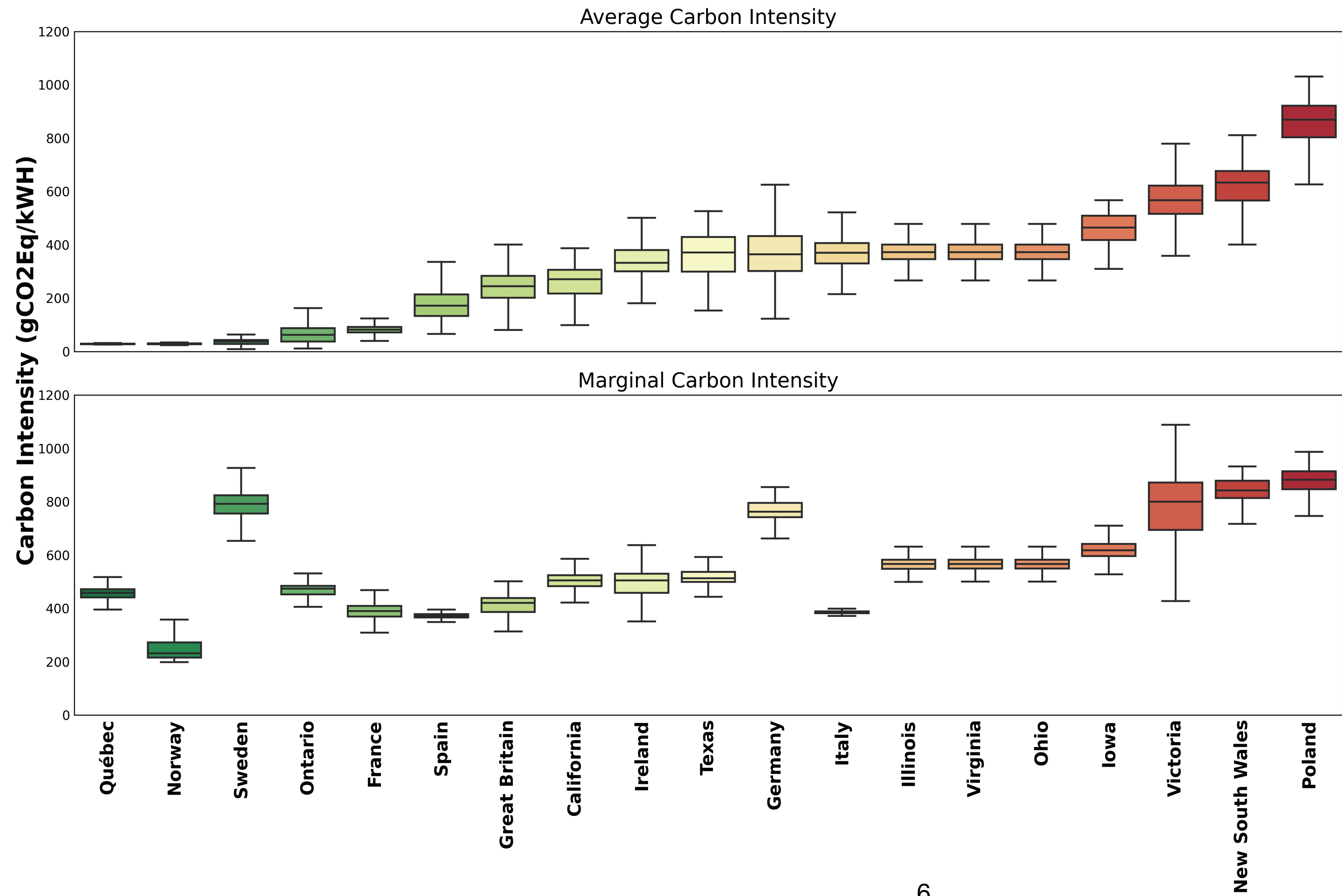result of additional load.

3

Short- and Medium-run Impact of Marginal Signal

Marginal CO2 Signal

works for **short-term** decision-making for **small** loads.

non-intuitive for **medium- to long-term** decision making and accounting

Electricity Demand

b_1

a_2

a_1

b_2

b_1

a_1

a_2

Base Load

t_0 t_1

t_i t_{i+1}

Time

Long-run Impact of Marginal Signal

Spatial Shifting Implications of Marginal and Average

Average Carbon Intensity

Marginal Carbon Intensity

Carbon Intensity (gCO2Eq/kWH)

Québec, Norway, Sweden, Ontario, France, Spain, Great Britain, California, Ireland, Texas, Germany, Italy, Illinois, Virginia, Ohio, Iowa, Victoria, New South Wales, Poland

Spatial Shifting Implications of Marginal and Average

Average Carbon Intensity

Italy has 19x average carbon intensity

Marginal Carbon Intensity

Italy has 0.5x marginal carbon emissions

Carbon Intensity (gCO2Eq/kWH)

Sweden
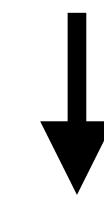
Italy
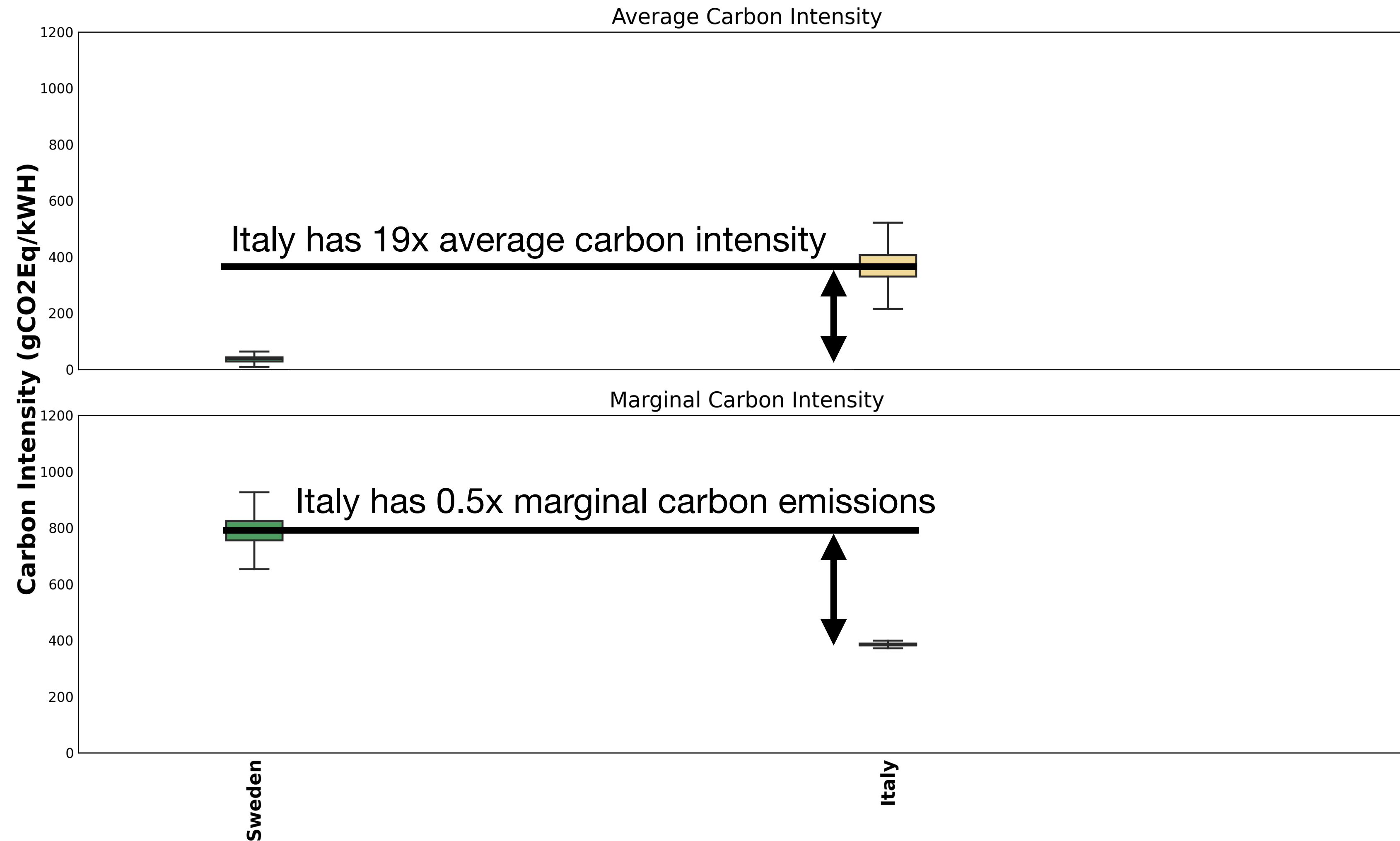
Scheduling based on marginal emissions **may pick dirty regions** as opposed to green regions.
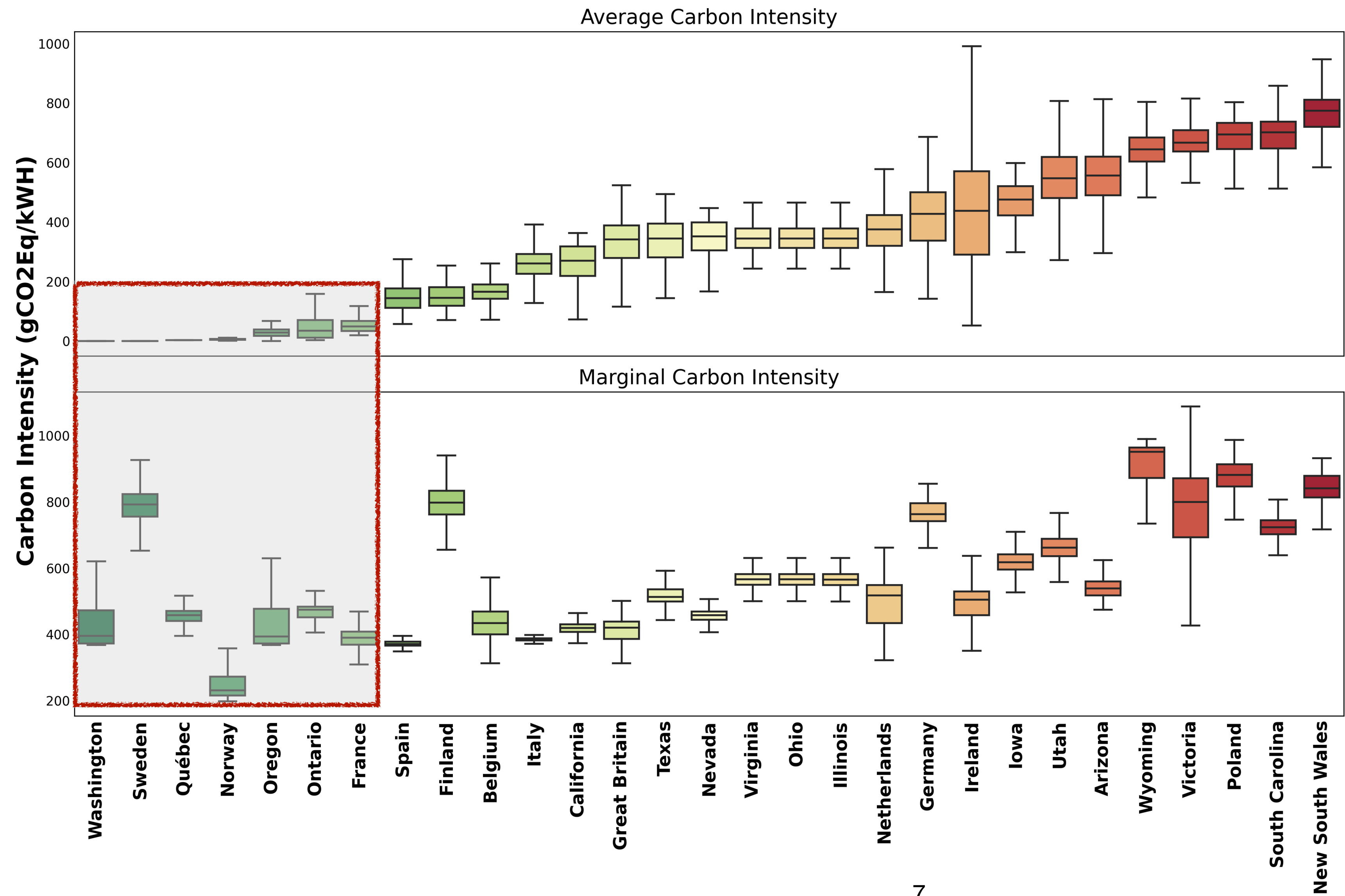
Spatial Shifting Implications of Marginal and Average

Is There a Consensus?

"Optimizing attributional emissions will aim to reduce a company's asset's emissions whereas optimizing based on consequential emissions will aim to reduce total system-wide emissions. If one wants to maximize global impact, then optimizing on **consequential emissions is the recommended** optimization target[1]."
- Olivier Corradi, Electricity Maps, Gavin McCormick, WattTime, Henry Richardson, WattTime, Trevor Hinkle

August 24, 2021

June 06, 2022

"Although the **average signal is not perfect**, our experience working with both signals shows that **it currently represents the best suited signal** for use in **automated real-time decisions**.[2]"
- Olivier Corradi, CEO @ Electricity Maps

March 18, 2022

"adopting the **LRMER could improve decision-making**, particularly by better capturing the projected role of renewable generators in the evolution of the power sector[3]"
- Pieter Gagnon, Wesley Cole, NREL

[1]https://www.watttime.org/app/uploads/2021/08/GHG-Frameworks-WhitePaper-Tomorrow-WattTime-202108.pdf

[2]https://www.electricitymaps.com/blog/marginal-vs-average-real-time-decision-making#fn-1

[3]Planning for the evolution of the electric grid with a long-run marginal emission rate

Summary

- ## Visibility is Possible

  - Multiple signals available.

  - No signal is perfect.

  - Work on developing better signals.

- ## Decision-making vs. Accounting

  - A signal best-suited for decision-making may not be good for accounting

  - Medium-run jobs are not considered by short-run or long-run marginal signals

Interested in Further Research?

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list of relevant conferences
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CarbonFirst Project Webpage
http://carbonfirst.org/

The Third ACM SIGEnergy Workshop on Society, Climate, and Sustainability
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2022 Participants: Amazon, Cornell, Duke, Meta, Microsoft, UCSC, UCSD, VMWare, & others.