Locational Marginal Emission Rates

The Market Signal Unlocking Smarter Carbon Decisions

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ESIG
ENERGY SYSTEMS INTEGRATION GROUP
2024 Fall Technical Workshop
Providence, Rhode Island
October 21 – 23, 2024

T C R

Climate Change, Carbon Emissions, and Net-Zero Targets

Corporations, universities, governmental entities, and more are motivated to track and reduce their carbon emissions, driven by concerns about the negative effects of climate change and new regulatory requirements

Aiming to achieve net-zero emissions and 24/7 carbon-free energy

Meta

Aiming for value chain net-zero emissions by 2030

Aiming to be carbon negative by 2030 and, by 2050, to remove from the environment all the carbon the company has emitted, either directly or by electrical consumption, since it was founded in 1975

Maryland Energy Administration

Aiming for 100% clean energy by 2035 and net-zero economy-wide GHG emissions by 2045

More than 300 universities in the U.S. have net-zero targets

Measure, Track, Reduce

If you cannot measure it, you cannot improve it.

- Lord Kelvin

GHG Protocol

- International standard for greenhouse gas (GHG) reporting developed by the World Resources Institute and World Business Council for Sustainable Development[1]

- Provides a standardized framework for calculating and reporting GHG emissions from a wide range of sources and classifies a company's GHG emissions into three scopes:

SCOPE 1
Direct GHG emissions that occur from sources that are owned or controlled by the company

SCOPE 2
Indirect GHG emissions from the generation of purchased electricity consumed by the company

SCOPE 3
Indirect GHG emissions from the activities of a company occurring at sources not owned or controlled by the company

[1] https://ghgprotocol.org/

Scope 2 Methodology

- Two approaches for quantifying GHG emissions from electricity usage are described in the guidance:
  - **Market-Based Method**: Allows organizations to match consumption with contractual instruments for renewable energy on a per-MWh basis
  - **Location-Based Method**: Uses average emission rate of the local grid to convert MWh of electricity consumption into emissions footprint

EXAMPLE

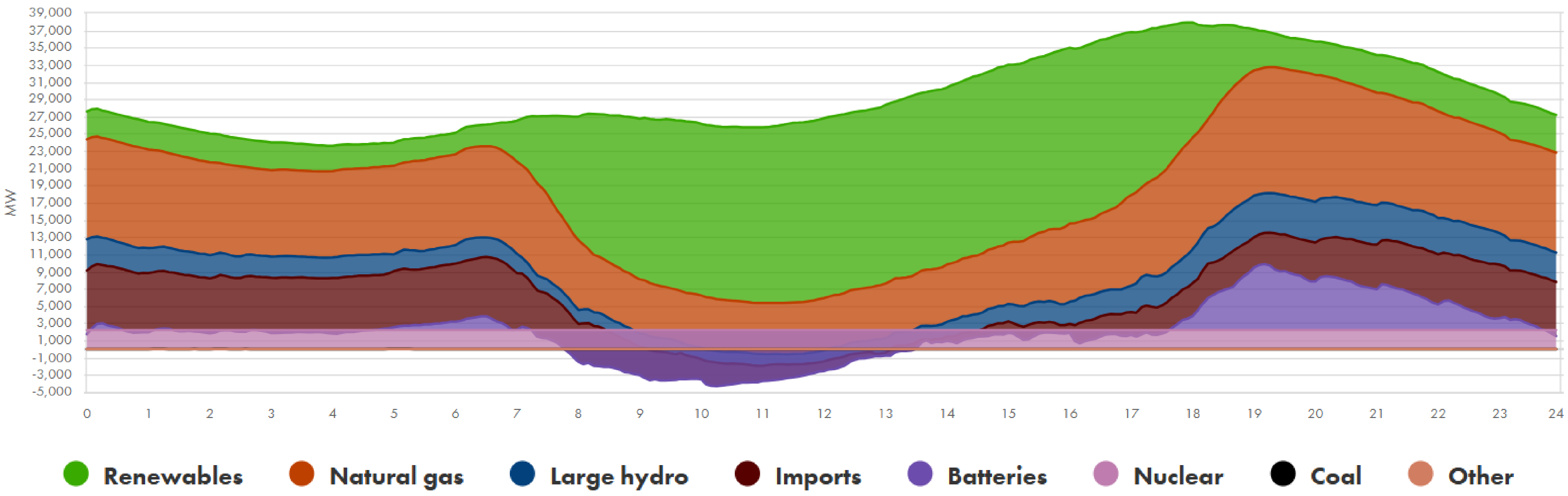
U.S. based company located in PJM with 100 GWh of load and 50 GWh of RECs, where the average emission rate of PJM is 811 lbs-CO_2/MWh :

$$\text{Emissions} = (100\text{ GWh} - 50\text{ GWh}) \times 811\text{ lbs-}CO_2/\text{MWh} = 40.5\text{ million lbs-}CO_2$$

All Renewable Energy Is Not Created Equal

- Renewable generation reduces grid emissions by offsetting the need for generation from other sources (e.g. fossil generators). The actual emissions impact of renewable generation depends on which competing generation is being displaced.

CAISO Supply, August 28, 2024

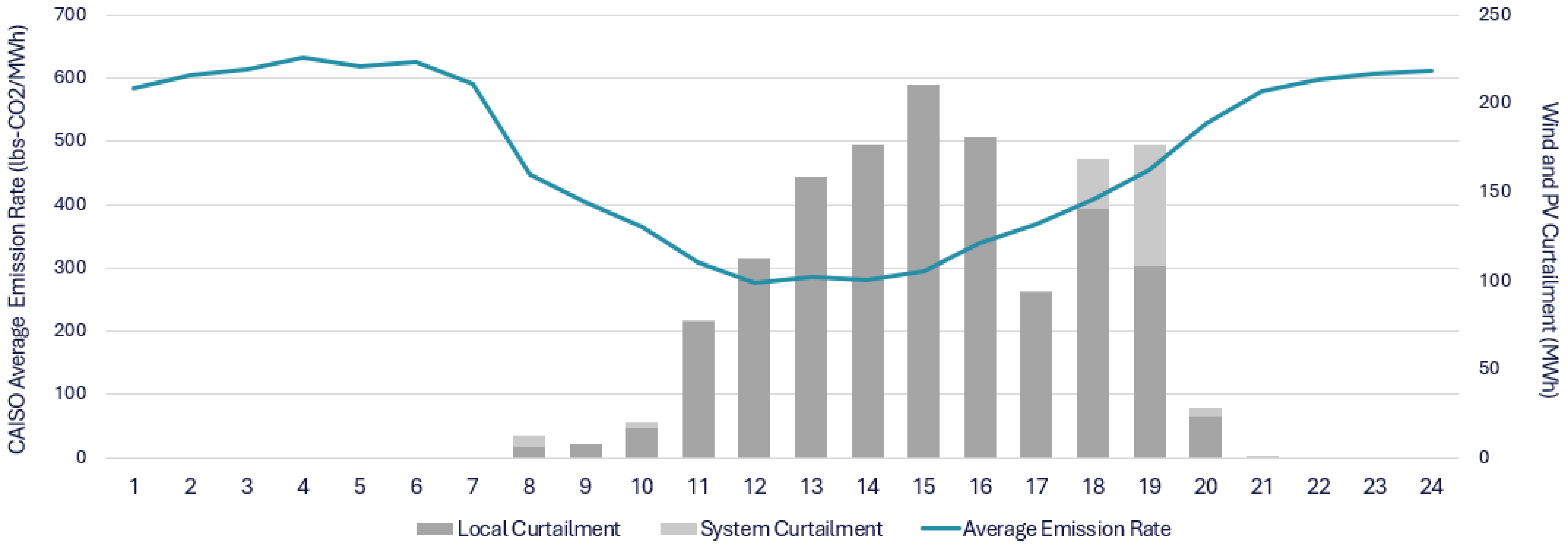


Credit: CAISO

All Renewable Energy Is Not Created Equal

- Average Emission Rates do not reflect the physics of grid emissions and may not send correct signals

CAISO Average Emission Rate and Renewable Curtailment, June 30, 2023



Data Source: CAISO

Understanding Marginal Emission Rates

- In an interconnected power system, an incremental injection/withdrawal of energy changes the system dispatch and, therefore, the carbon emissions

The **Locational Marginal Emission Rate** (LMER) measures the change in system-wide emissions in response to a marginal increase or decrease in demand at a given node:

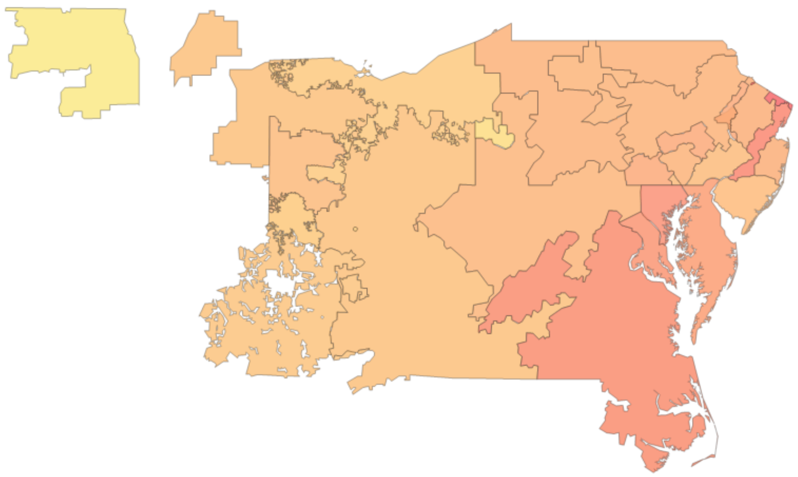
$$LMER_{node} = \frac{\partial (CO_2)_{system}}{\partial (Demand)_{node}}$$

[1] Aleksandr Rudkevich, Pablo A. Ruiz. "Locational Carbon Footprint of the Power Industry: Implications for Operations, Planning and Policy Making." In: Q.P. Zheng et al. (eds.), "Handbook of CO2 in Power Systems," Energy Systems, DOI 10.1007/978-3-642-27431-2_8, # Springer-Verlag Berlin Heidelberg 2012, pp. 131 – 165.

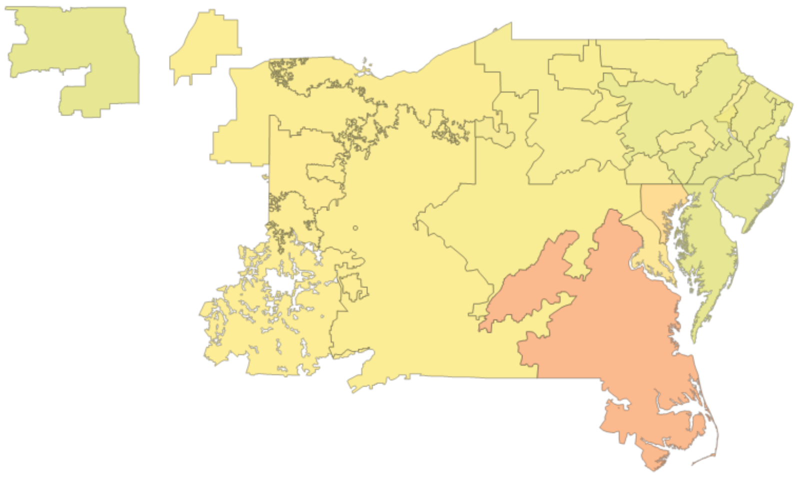
PJM Marginal Emission Rates

- Marginal emission rates exhibit geographic variability. Between power markets, differences in generation mix cause large differences in MERs. Within a single market, transmission constraints can cause MERs in one area to be higher than another.

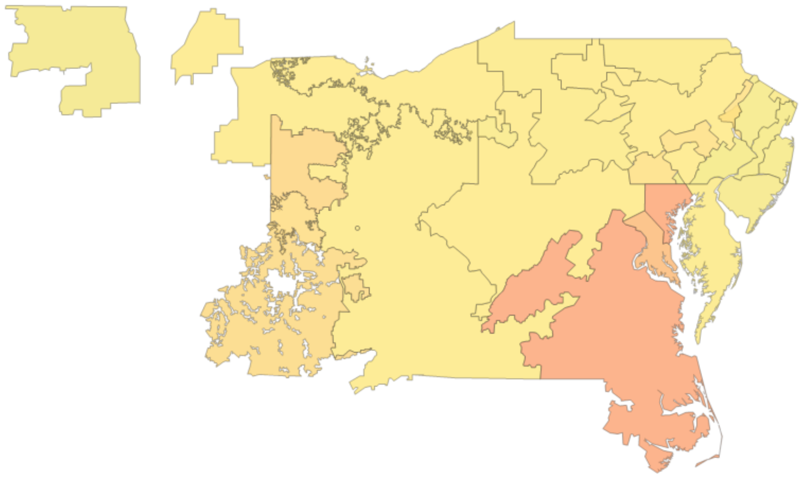
Winter ‘22 (Jan-Feb)



Spring ‘22 (Mar-May)



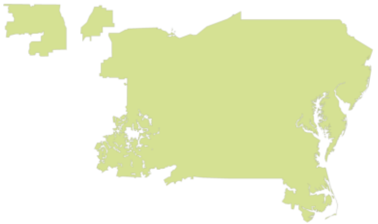
Summer ‘22 (Jun-Aug)



Marginal Emission Rate (lbs-CO_2/MWh)

0	250	500	750	1,000	1,250	1,500

Data Source: PJM Data Miner

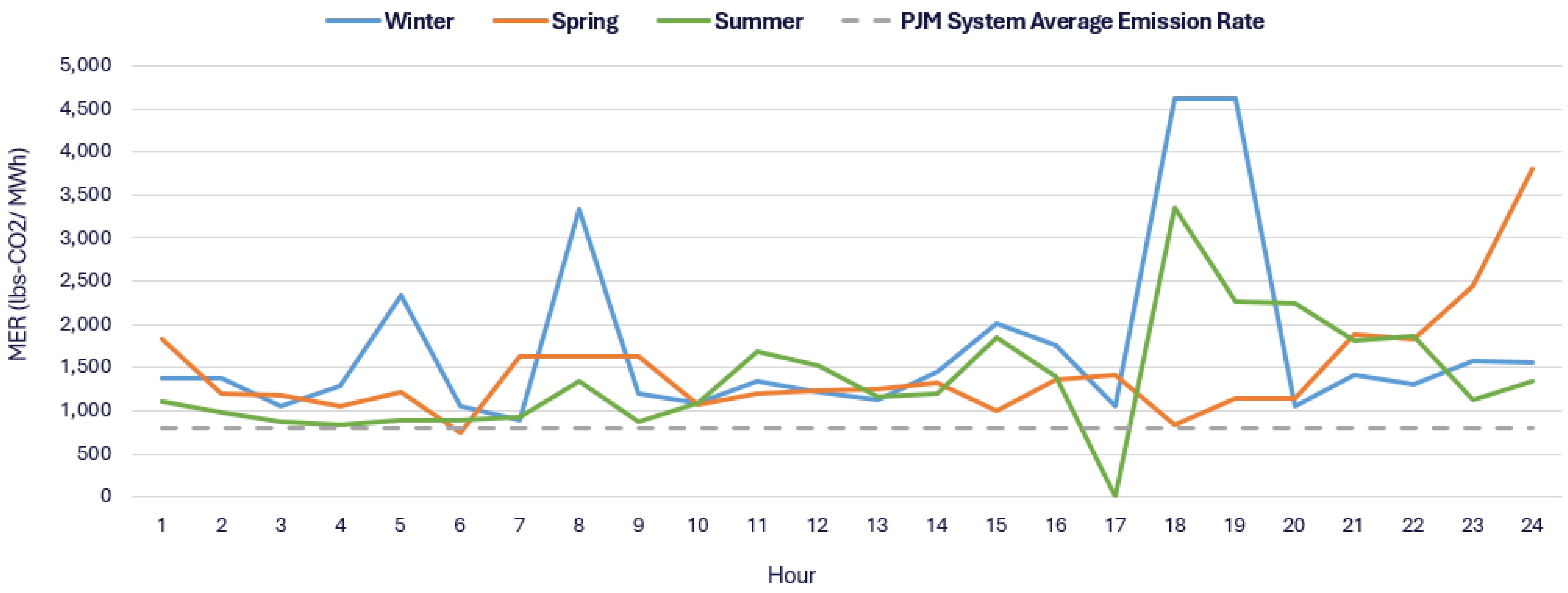


PJM Annual System Average Emission Rate (2022)

PJM Marginal Emission Rates

- Marginal emission rates exhibit intraday volatility as changes in net demand result in a change in the system economic dispatch and the marginal generators.

Marginal Emission Rate on Representative Sample Days in BGE



Data Source: PJM Data Miner

How LMERs Can Advance Grid Decarbonization

01 Siting renewable development/procurement[1]

- LMERs help developers and buyers optimize site selection to maximize carbon displacement per dollar investment

02 Provides operational signal for load/DER and storage

- LMERs serve as an intraday signal guiding the operation of DER and battery storage to minimize grid emissions

03 Mechanism for precise carbon accounting

- LMERs accurately reflect the operational physics of the power system and provide a mathematically sound way to quantify the carbon impact of all system components

[1] Hank He, et al. “Cost and emissions impact of voluntary clean energy procurement strategies." The Electricity Journal, Volume 37, Issue 3, 2024.

Quantifying the Emissions Impact of System Elements

Emissions Impact Formulas

Consumption

$$E(t) = Load(t) \times LMER(t)$$

The emissions impact of **electricity consumption** at a specific location and time is calculated as the quantity of electricity consumed multiplied by the LMER for that location and time.

Generation

$$E(t) = Generation(t) \times [R - LMER(t)]$$

The emissions impact of **generation** at a specific location and time is calculated as the quantity of generation mult-iplied by the difference between the generator's physical emission rate and the LMER for the location and time.

Transmission

$$E(t) = Flow(t) \times [LMER_{from}(t) - LMER_{to}(t)]$$

The emissions impact of **transmission** is calculated as the differential of the marginal emission rate multiplied by the flow.

[1] Aleksandr Rudkevich, Pablo A. Ruiz. "Locational Carbon Footprint of the Power Industry: Implications for Operations, Planning and Policy Making." In: Q.P. Zheng et al. (eds.), "Handbook of CO2 in Power Systems," Energy Systems, DOI 10.1007/978-3-642-27431-2_8, # Springer-Verlag Berlin Heidelberg 2012, pp. 131 – 165.

Carbon Accounting Using Marginal Emission Rates

Carbon Footprint Theorem[1]

In an electric grid, the sum of carbon emissions from all grid elements – consumption, generation, and transmission – at any given point in time exactly equals the total mass of carbon emitted within a grid at the same point in time.

Achieving Net Zero

An entity achieves net-zero emissions status when the sum of emissions attributed to its consumption, generation, and transmission equals zero.

Consumption

$$\sum_{i}\sum_{t} Load_i(t) \times LMER_i(t)$$

Generation

$$\sum_{j}\sum_{t} Emissions_j(t) - Gen_j(t) \times LMER_j(t)$$

Transmission

$$\sum_{k}\sum_{t} Flow_k(t) \times \left[LMER_{from}(t) - LMER_{to}(t)\right]$$

[1] Aleksandr Rudkevich, Pablo A. Ruiz. "Locational Carbon Footprint of the Power Industry: Implications for Operations, Planning and Policy Making." In: Q.P. Zheng et al. (eds.), "Handbook of CO2 in Power Systems," Energy Systems, DOI 10.1007/978-3-642-27431-2_8, # Springer-Verlag Berlin Heidelberg 2012, pp. 131 – 165.

Case Study

Decarbonizing Maryland’s Electricity Sector

Disclaimer

The results presented are based on a study TCR is conducting for the Maryland Energy Administration (MEA). The study is ongoing, so all results presented are preliminary.

The opinions and positions expressed in this presentation are those of the study authors and do not necessarily reflect the opinions and positions of MEA. Any errors and omissions are the sole responsibility of the authors.

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Maryland Energy Administration

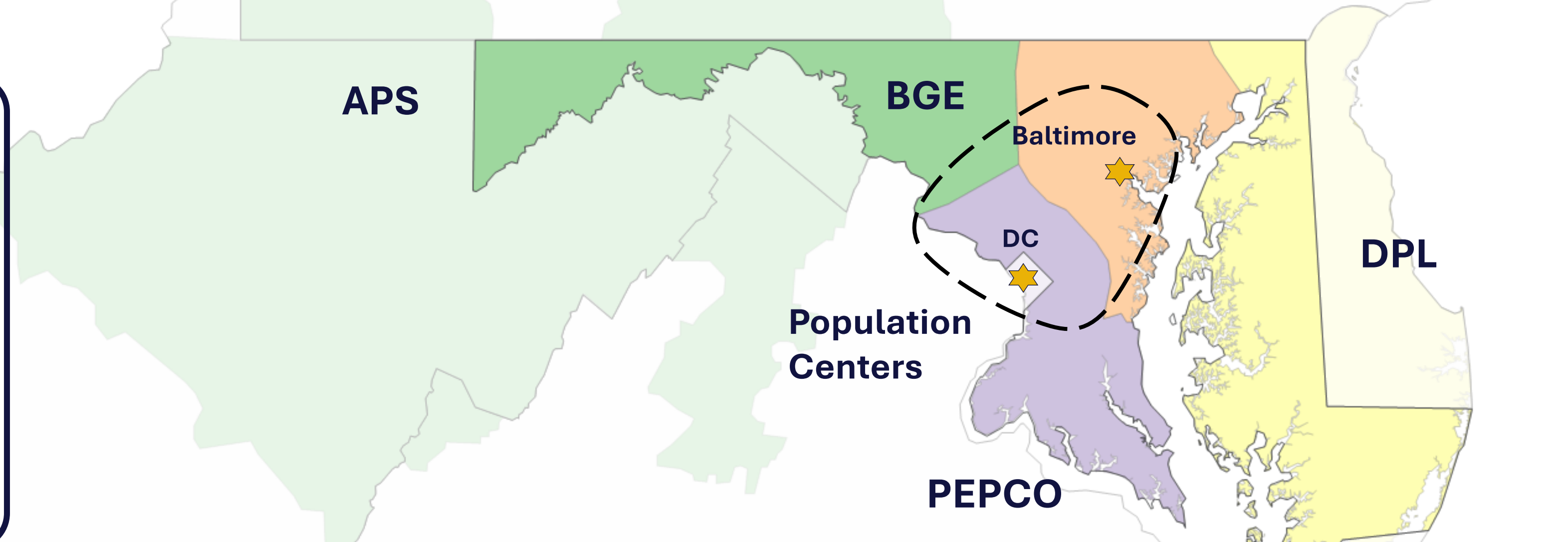
Maryland's Climate Goals

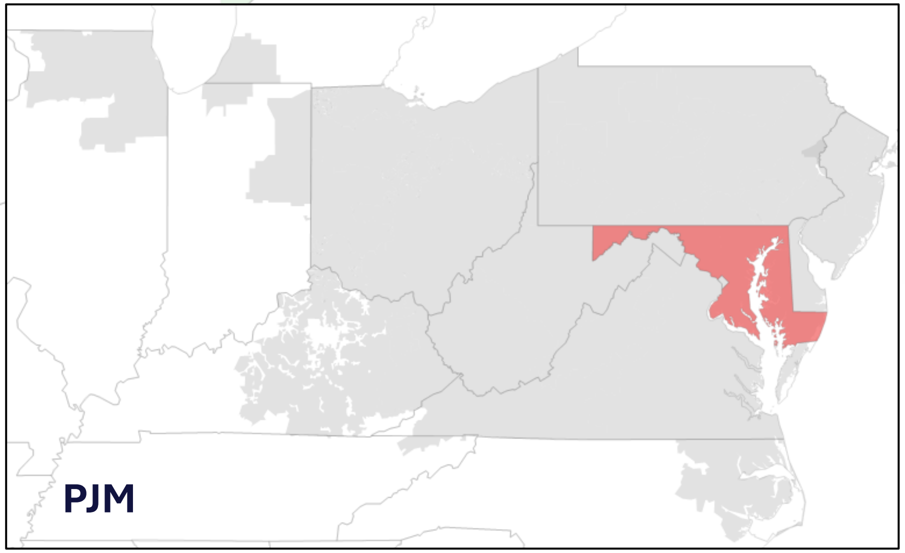
Policy Goals

Maryland's Climate Pollution Reduction Plan[1] outlines a path to net-zero GHG emissions by 2045 and establishes a new Clean Power Standard, requiring 100% clean energy by 2035.

Challenge

Maryland is a member-state of PJM. In an RTO, load in one state may be served by generation located in another state, making the attribution of carbon emissions more complicated.





Developing a Pathway to Decarbonization

01 **Quantify Maryland's electric sector carbon footprint for 2022**

02 **Develop a Base Case capacity expansion model to simulate capacity expansion across PJM in a business-as-usual environment**

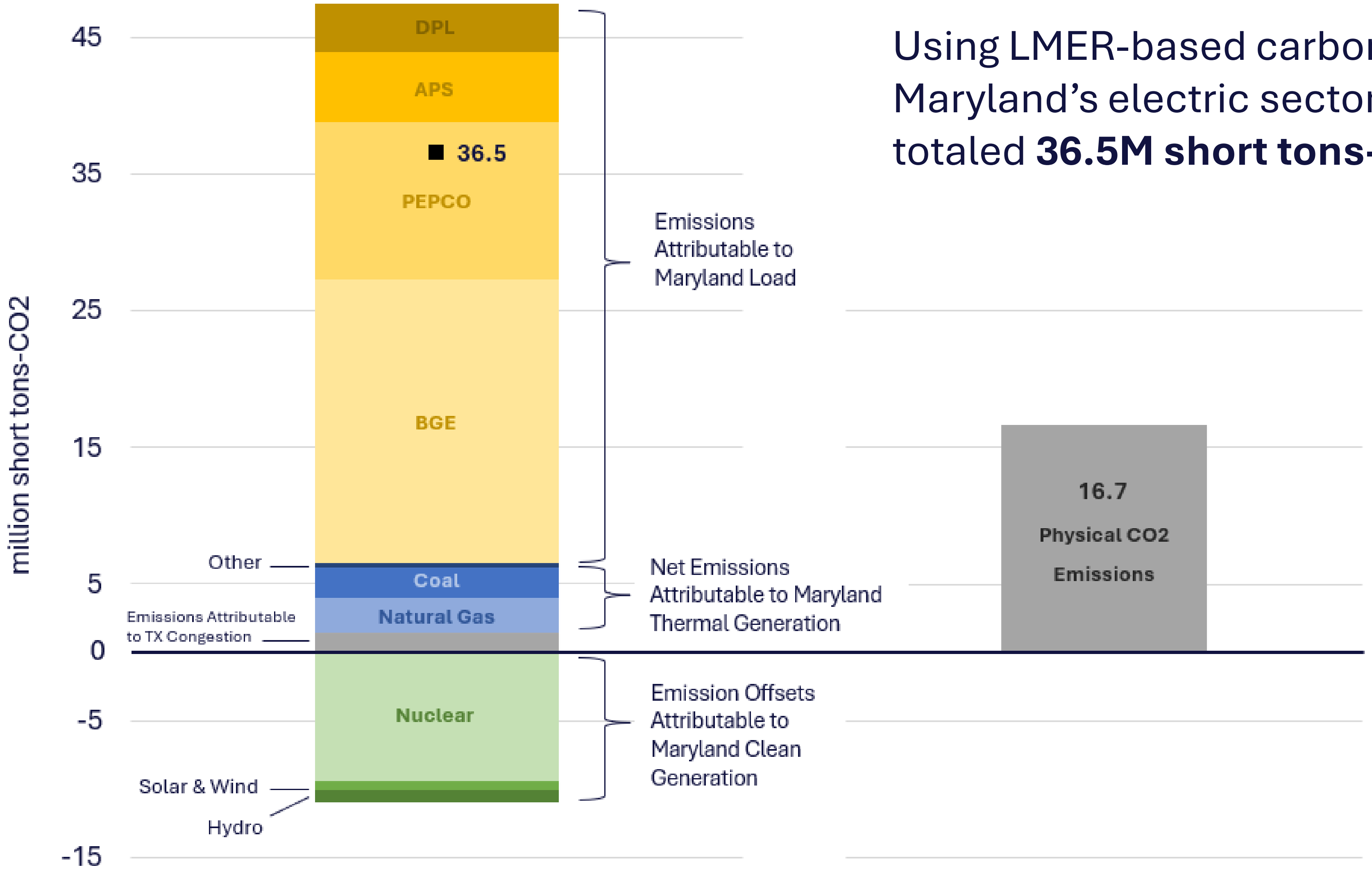
- Run economic dispatch model and calculate Maryland's simulated carbon footprint in the Base Case scenario using the LMER-based carbon accounting methodology

03 **Add additional constraints to the capacity expansion model to force Maryland's carbon footprint to zero by 2035**

- Provides the additions and retirements needed to achieve net-zero

04 **Re-run economic dispatch model using the new capacity expansion results and calculate Maryland's simulated carbon footprint again to confirm net-zero emissions was achieved**

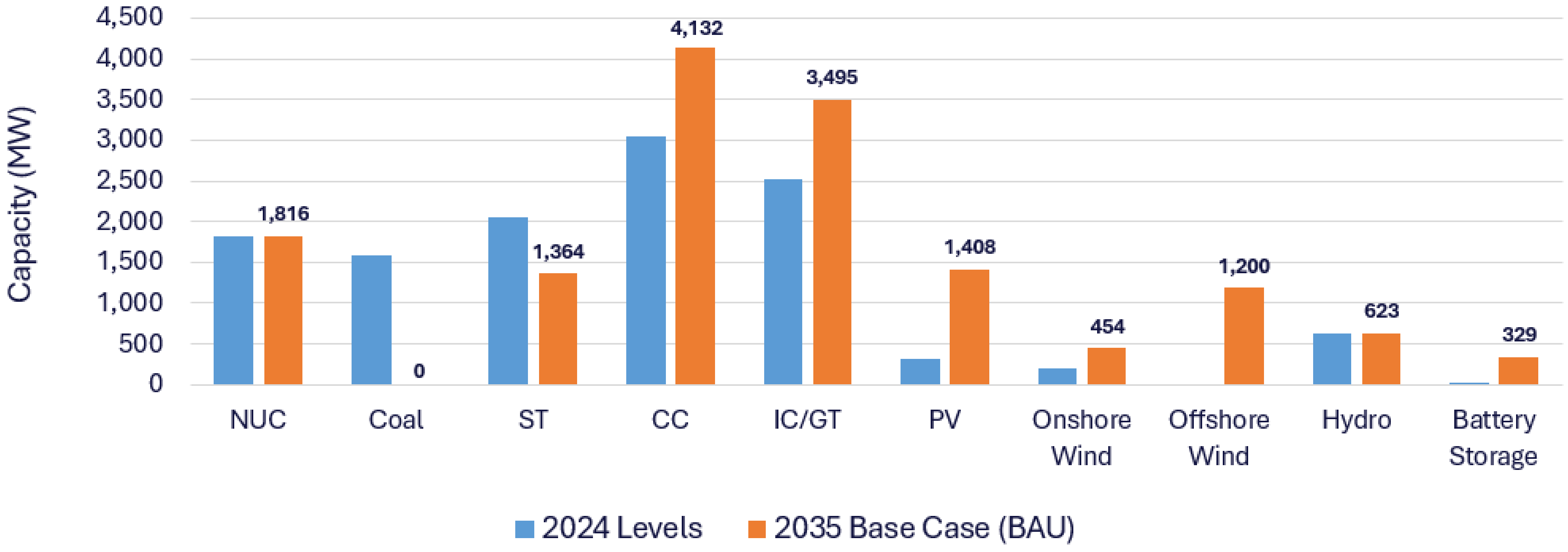
Maryland's Electric Sector Carbon Footprint for 2022



Using LMER-based carbon accounting, Maryland's electric sector carbon footprint totaled **36.5M short tons-CO2 in 2022**

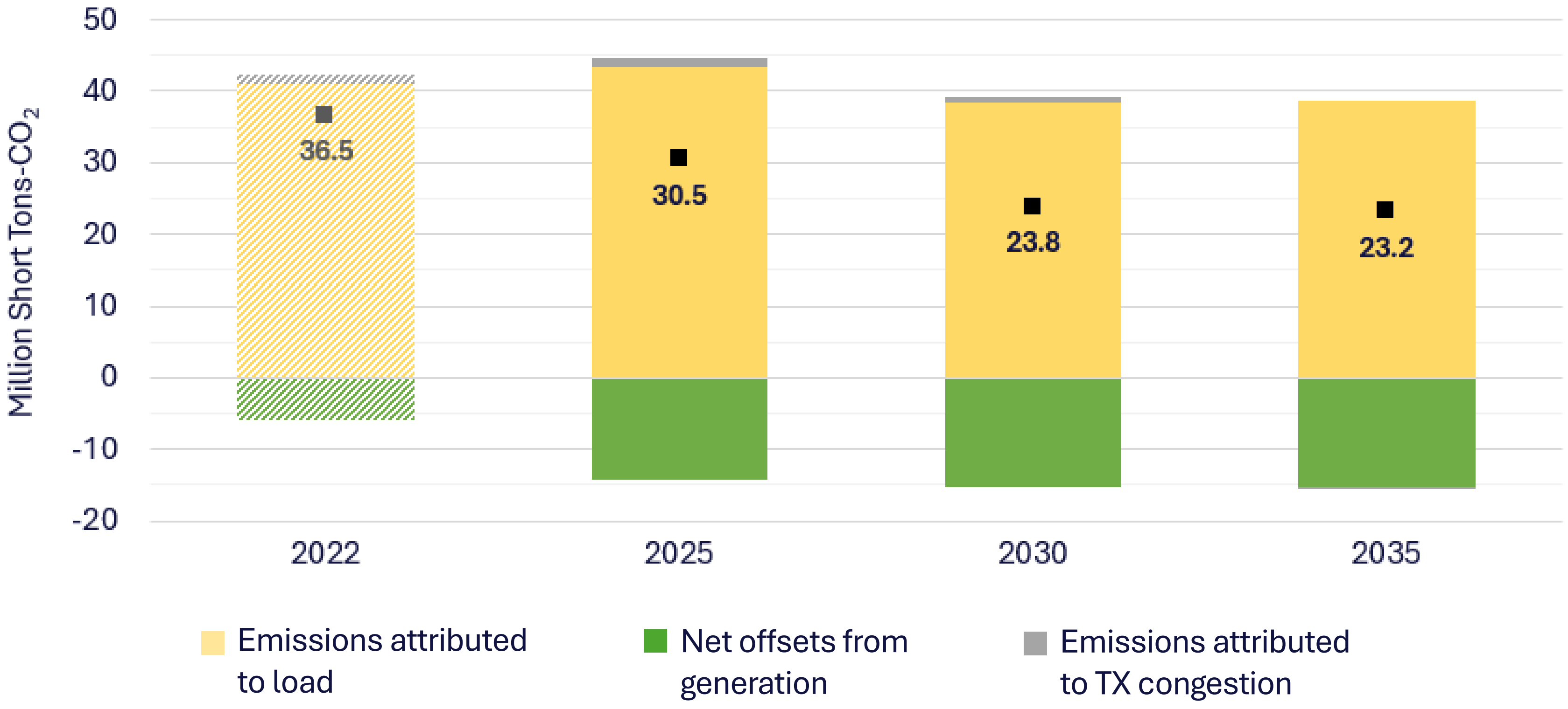
BAU Base Case – Capacity Expansion Results

- Under the BAU capacity expansion, the model adds 913 MW of PV, 264 MW of onshore wind, and 144 MW of offshore wind in Maryland on top of scheduled additions. Almost all retirements in the BAU capacity expansion are planned retirements, with the model choosing to also retire a small ST unit on the campus of UMD.



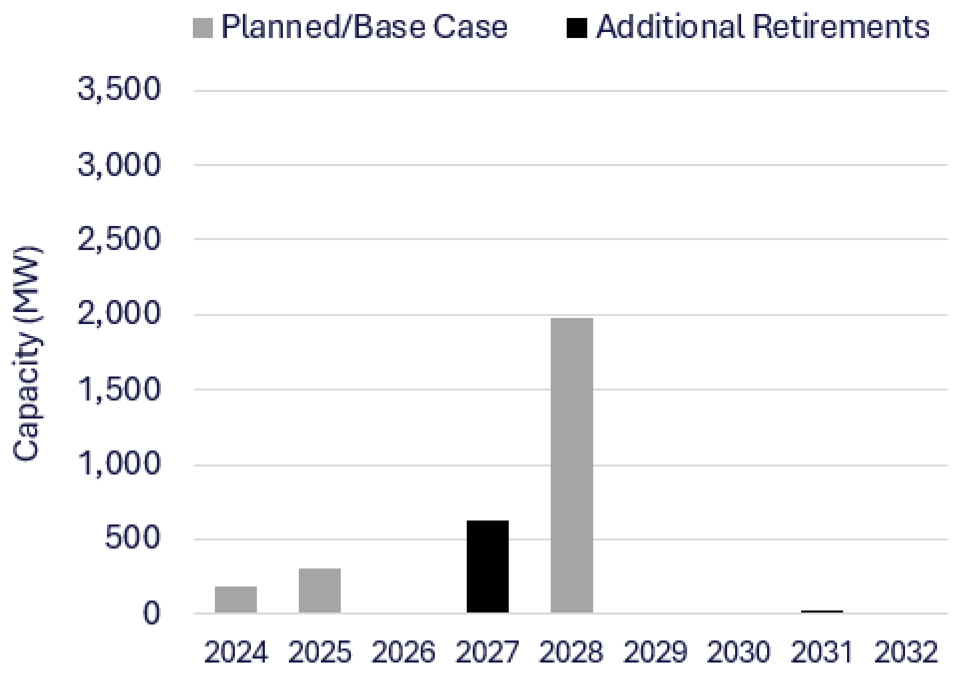
Maryland's Carbon Footprint In BAU Base Case

- Under the BAU capacity expansion, Maryland's electric-sector carbon footprint decreases to 23.2M short tons-CO2 by 2035. Net-negative emissions from Maryland generation offsets less than half the emissions attributable to Maryland's load. Emissions attributable to congestion decreases over time as the model builds near load centers.

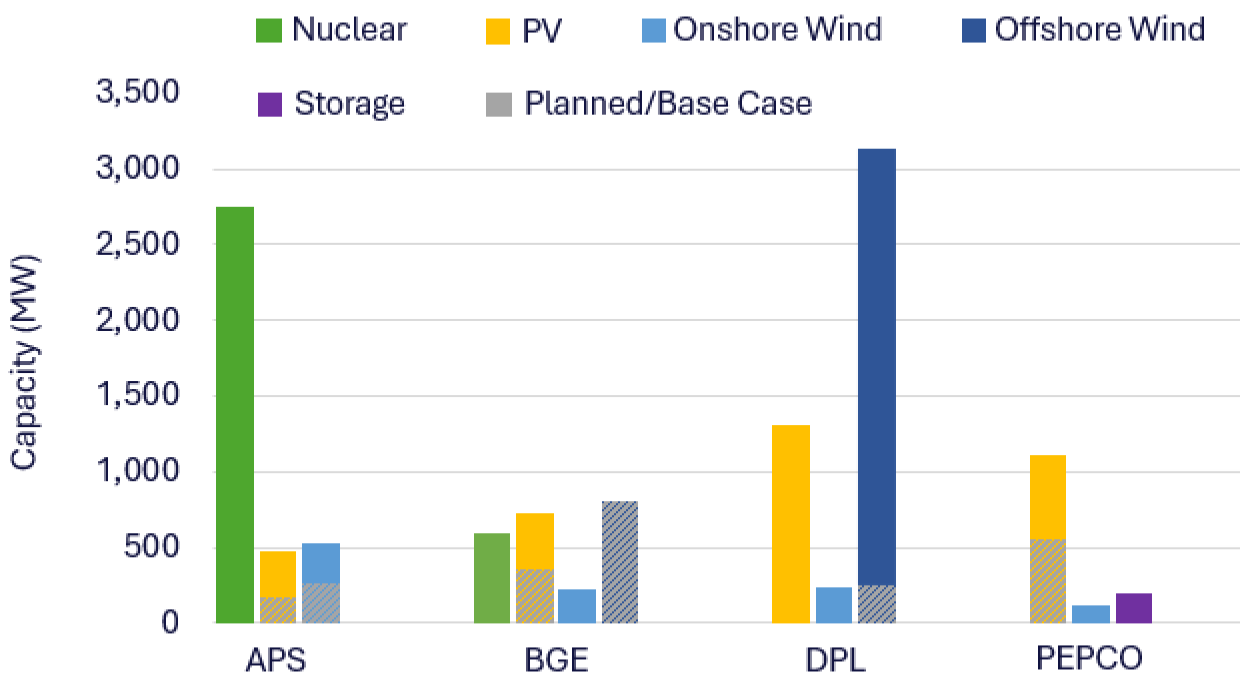


Additions/Retirements in Decarbonization Scenario

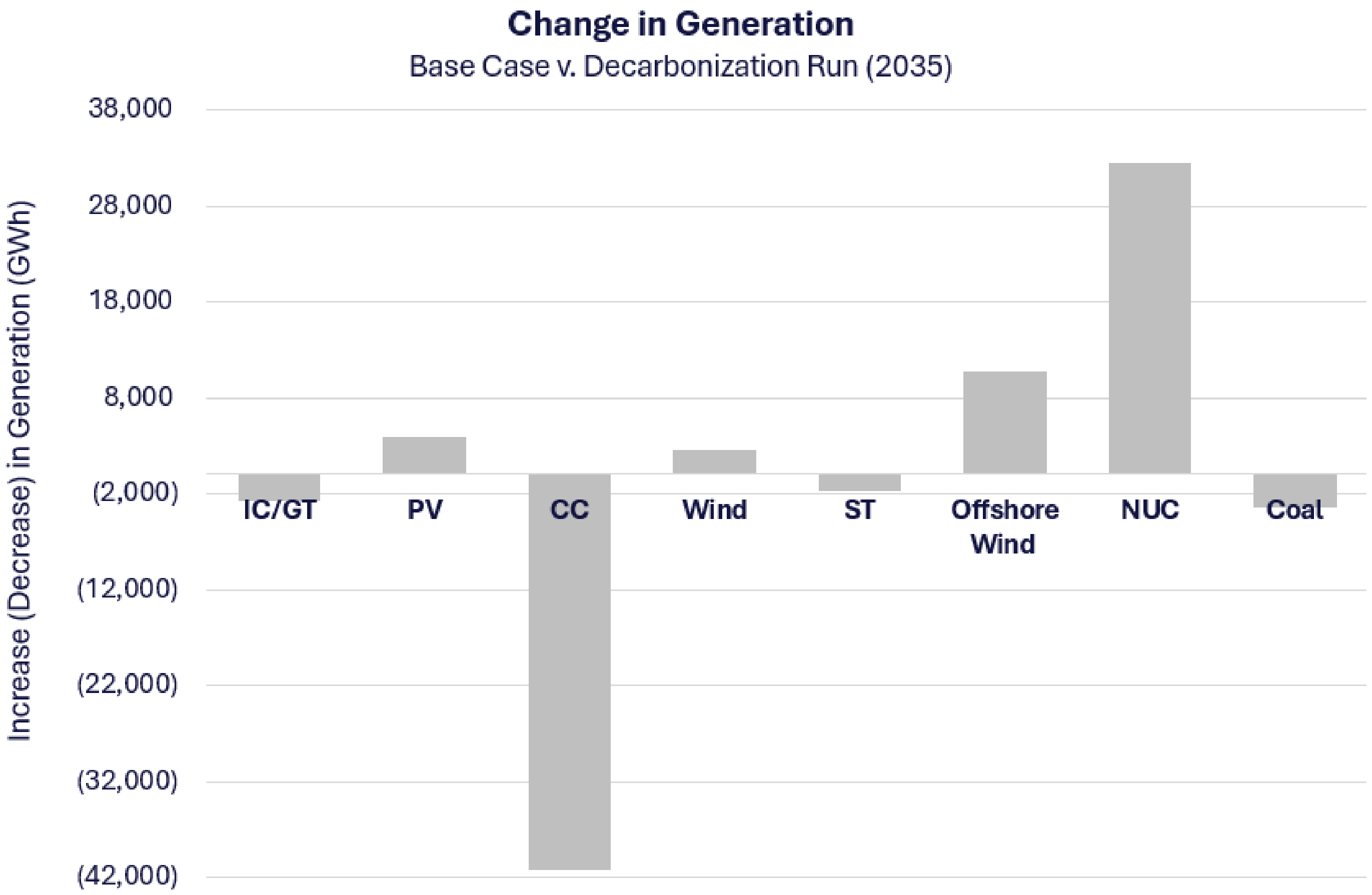
- Under the Decarbonization Scenario, the model retires an additional 632 MW of thermal capacity by 2032

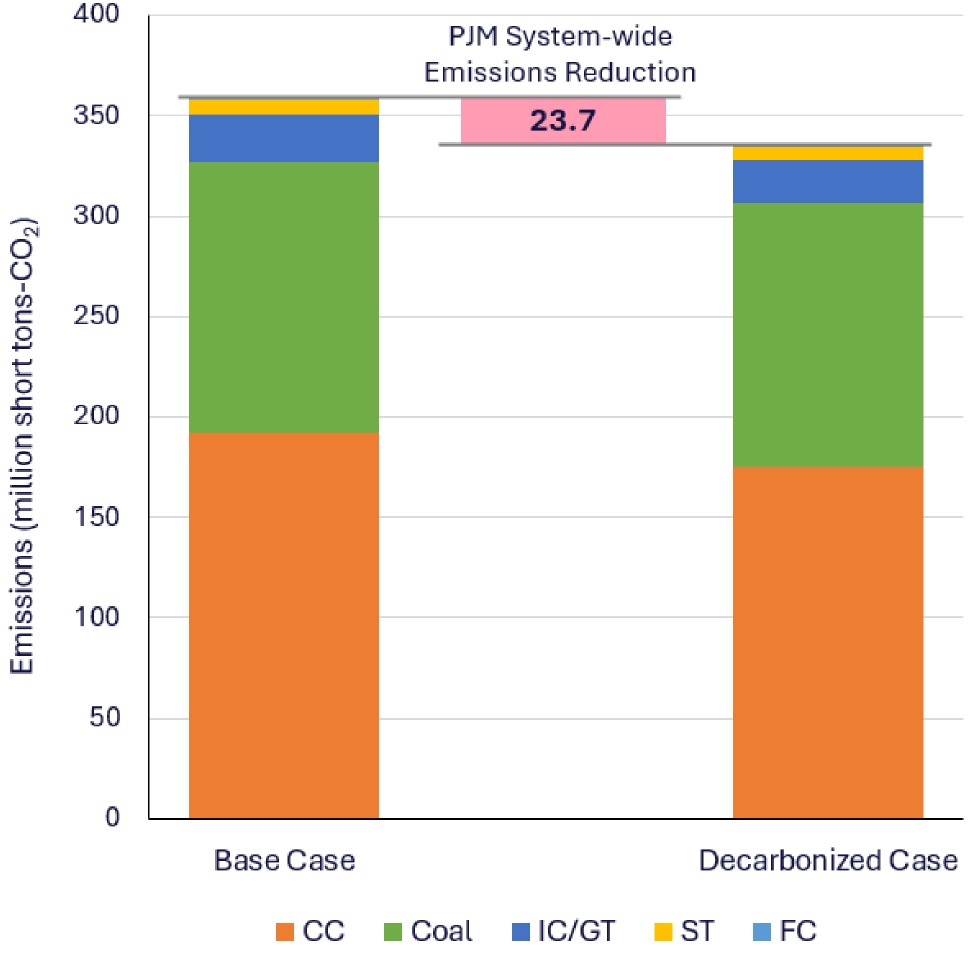


- Under the Decarbonization Scenario, the model adds an additional 9.6 GW above planned & BAU capacity expansion levels to reach a net-zero carbon footprint by 2035



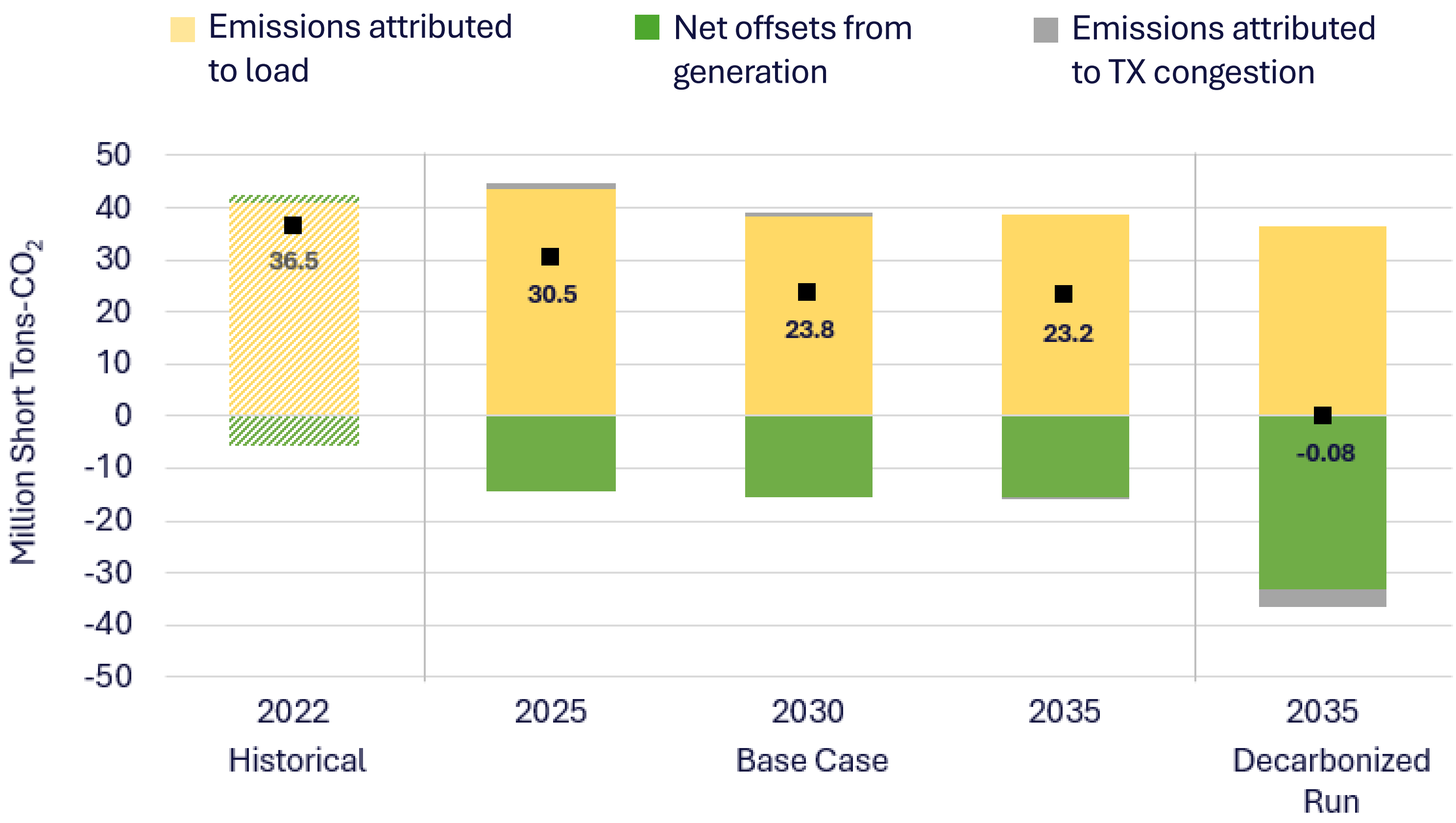
Change in PJM System-Wide CO_2 Emissions





Maryland's Carbon Footprint In Decarbonization Scenario

- Under the Decarbonization Scenario, net-negative emissions from Maryland Generation doubles relative to the Base Case due to higher levels of clean energy capacity



THANK YOU

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