Summary Impact of RGGI on Electricity Prices and Generation Fleet Operation in the PJM Interconnection

White Paper

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February 15, 2025

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Abstract

The objective of this white paper is to provide a detailed analysis of the environmental and economic impacts of the Regional Greenhouse Gas Initiative (RGGI) on consumers in the PJM Interconnection (PJM) given current state-level participation in RGGI. The paper begins with a short summary of the background and impact of RGGI since its inception in 2009, specifically with regard to the PJM market. Next, we present the results of a quantitative analysis exploring the impact of RGGI given today's generation mix. The results of the analysis indicate that the PJM wholesale market would provide lower cost energy to consumers and result in lower system-wide carbon dioxide (CO2) emissions were RGGI not implemented in any PJM state.

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Executive Summary

This paper briefly summarizes the history of the Regional Greenhouse Gas Initiative (RGGI) within the footprint of the PJM Interconnection (PJM) and quantitatively evaluates the current economic and environmental impact of RGGI within that footprint.

The historical overview of the RGGI program indicates that the three PJM states that currently participate in RGGI – Delaware, Maryland, and New Jersey – have collectively reduced in-state carbon dioxide (CO2) emissions by 46% over the period 2009 to 2023. In Delaware and Maryland, both of which have remained in the program since its inception, the joint reduction was 61%. Through the end of 2023, the states of Delaware, Maryland, and New Jersey have received a total of $1.4 billion in auction revenues, which have been used to support multiple energy related projects in those states.

The quantitative evaluation is based on power market simulations performed by Tabors Caramanis Rudkevich Inc. (TCR) for two simulation scenarios – the Business as Usual (BAU) Case and the No RGGI Case. The BAU Case reflects the current condition in which RGGI is implemented in the states of Delaware, Maryland, and New Jersey. The No RGGI Case assumes that there is no PJM-state participation in RGGI. Under both scenarios, TCR modeled the PJM wholesale electricity market over a one-year time period from January 1, 2025 through December 31, 2025. Under the BAU Case, TCR assumes that all generating units located in Delaware, Maryland, and New Jersey incorporate a RGGI allowance cost of $20 per short ton (2000 pounds) of CO2 into their energy offers.[1]

TCR arrived at several observations from the comparison of these two scenarios:

- ❖ RGGI negatively affects consumers within the PJM footprint both economically and environmentally. Indeed, continuation of the RGGI program in its current form causes:
  - an increase in annual system-wide CO2 emissions of 2.7 million short tons; and
  - an increase in annual cost to serve consumer load in every PJM pricing zone totaling $1.16 billion across all zones.[2]

It is clear from the comparison of the two scenarios that the continuing participation of PJM states in the RGGI program in its current form contradicts RGGI's principal intent, which is to reduce greenhouse gas emissions. At the same time, the program causes unjust economic harm, i.e., higher costs to consumers throughout PJM. The primary beneficiaries of this

[1] $20 per short ton of CO2 reflects the RGGI forward price in October 2024, when work on this paper began. Prices have consistently been near or above this level over the past year.

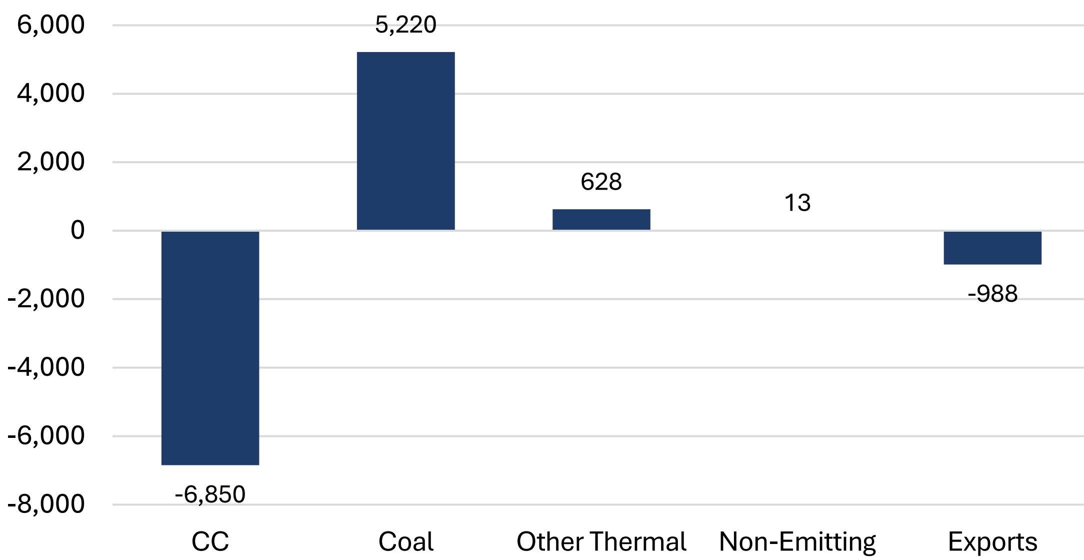
[2] All financial results are reported in constant 2024 dollars.

program are generating units located in non-RGGI participating PJM states that receive a total annual revenue increase of nearly $1.3 billion. The revenues of generating units located in participating states are reduced by $0.5 billion, resulting in an $825 million net increase in generator revenues.

The allowance cost imposed by RGGI has the direct effect of altering the merit order of generating units in PJM. As shown in Figure 1, the assumed $20 per short ton RGGI allowance price renders highly efficient combined-cycle (CC) power plants in RGGI participating states uneconomic, while creating opportunities for coal-fired units in the neighboring states to be dispatched more frequently in the energy market. This results in higher emissions from coal-fired and other less efficient thermal power plants while reducing emissions from gas-fired CC plants. The net result, shown in Figure 2, is increased system-wide CO2 emissions totaling 2.7 million short tons over the study year.

FIGURE 1

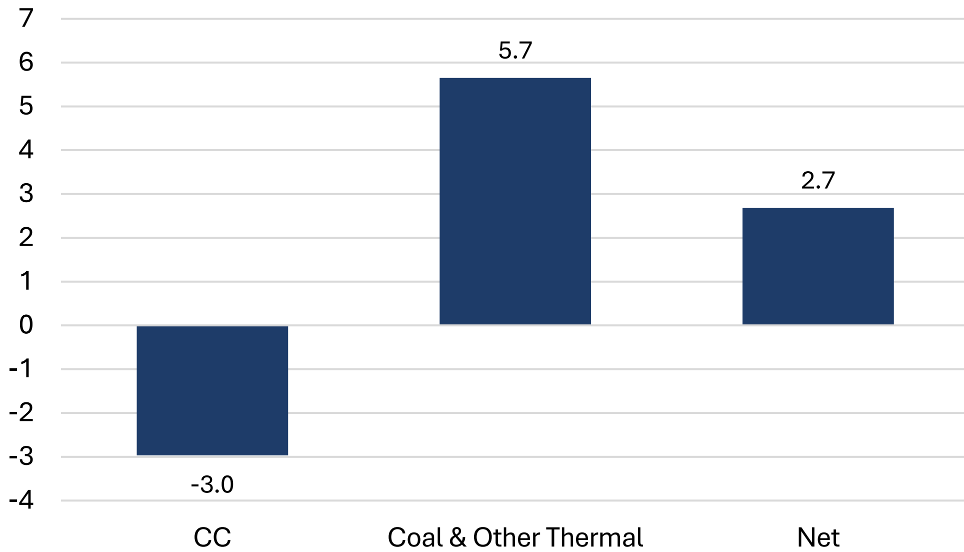
Impact of RGGI on PJM Generation (GWh)



Notes: Value shown is the increase (decrease) in generation between the No RGGI Case and the BAU Case.

FIGURE 2

Impact of RGGI on CO_2 Emissions in PJM (Million Short Tons)



Notes: Value shown is the increase (decrease) in CO2 emissions between the No RGGI Case and the BAU Case.

1. A Brief History of RGGI and PJM State Participation

RGGI was the first market-based, mandatory greenhouse gas emissions market in the United States. Initiated by then Governor George Pataki of New York, a Memorandum of Understanding (MOU) was signed in December 2005 by the governors of Connecticut, Delaware, Maine, New Hampshire, New Jersey, New York, and Vermont. In 2007, the states of Massachusetts, Maryland, and Rhode Island joined. New Jersey withdrew from RGGI in 2013 and later rejoined in 2019. Virginia joined RGGI in January 2021 but has since withdrawn after multiple legal challenges. Pennsylvania formally joined RGGI in April 2022, however, its participation in RGGI has also been mired in ongoing litigation. Neither Virginia nor Pennsylvania are modeled as RGGI participating states in our quantitative analysis.

The goal of RGGI is to implement a cap-and-trade market to reduce CO2 emissions from the electric power sector. At the highest level, RGGI sets an annual regional cap on CO2 emissions that is applied across all power plants greater than 25MW in the participating states. Generators are required to bid at auction to purchase tradable CO2 allowances to cover their emissions. Each allowance represents authorization to emit one short ton of CO2. The initial cap was structured to decline by 2.5% annually. The cap was reset in 2018 to account for New Jersey rejoining RGGI.

RGGI emission allowances are sold at auction on a quarterly basis to any qualified buyer. A Cost Containment Reserve (CCR) is used to prevent allowance prices from rising above a ceiling price. When prices approach the ceiling, which was $15.92 per short ton for 2024, RGGI adds allowances to the supply pool to hold costs below the ceiling. There is also an Emissions Containment Reserve (ECR) that functions to remove allowances from the market if prices drop below a predetermined level, which was set at $6.35 per short ton for 2024.[3]

In addition, there is a highly active secondary market for RGGI allowances. The gross trading in secondary allowances is frequently a multiplier of 1.2 to 1.4 or higher as a function of the uncertainty in multiple elements of the electricity market. The secondary market provides a source of allowances during periods between auctions, provides a mechanism for hedging the cost of allowances, and the forward market provides economic signals for the energy offers of generators and for potential investment.

[3] See RGGI CO2 Emissions Dashboard | RGGI, Inc. for detailed auction and emissions data.

The success of RGGI from 2009 to 2023 was significant in that the RGGI states collectively reduced their carbon emissions by 44 million short tons, or roughly 36%, as shown in Figure 3.[4] RGGI reports that the total revenue from the auction of emission allowances for the 14-year period of $8,616,386,174 was returned proportionately to the participating states, where it was then applied broadly to programs within the electric sector that ranged from load management to other programs for emissions reduction.

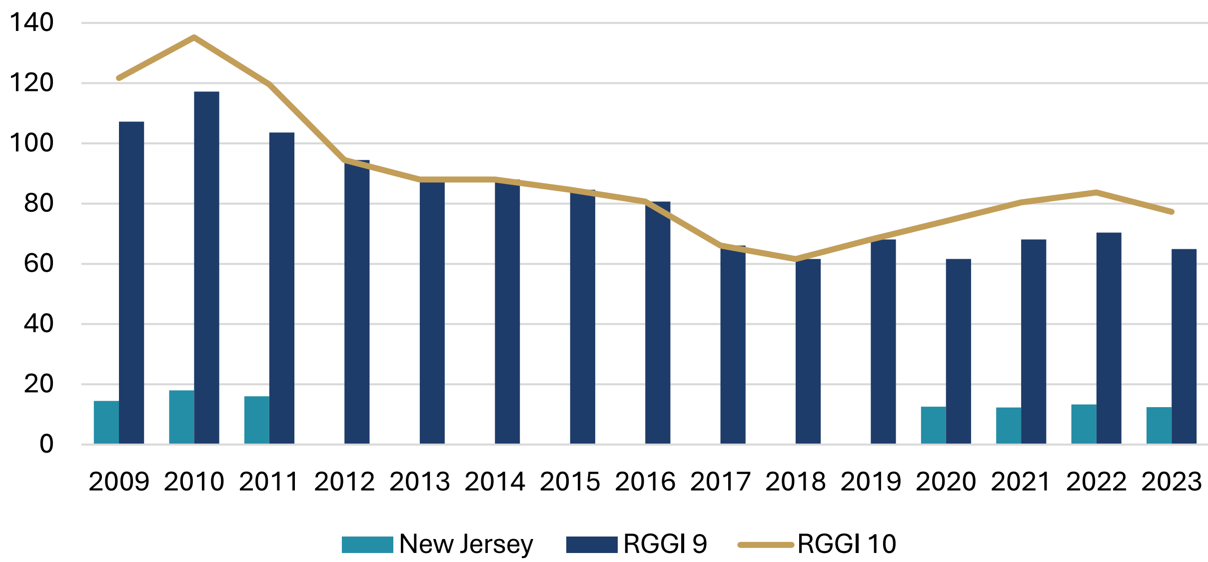
During the period 2009 to 2023, New Jersey participated in RGGI from 2009 through 2011 and again from 2020 to the present. RGGI reports its statistics as "RGGI 10" when including New Jersey and as "RGGI 9" when excluding New Jersey. From 2009 to 2023, the three RGGI participating states in PJM (Delaware, Maryland, and New Jersey) reduced their total CO2 emissions by 20.5 million short tons, or roughly 46%, as shown in Figure 4. Delaware and Maryland alone reduced their emissions by 61%. Auction revenues returned $2,669,667,414 to the three states, with over $1.4 billion going to Maryland, $945 million to New Jersey, and $310 million to Delaware.

The conclusion one reaches with respect to CO2 emissions reductions is that RGGI has been a success throughout the RGGI states, and that even with the minimal participation of three PJM states, PJM RGGI members accounted for 20.5 million short tons, or 46%, of the total 44.4 million short tons of CO2 reductions across all of RGGI. PJM states received auction revenue returns equivalent to 31% of the total revenues reported by RGGI. However, as this analysis demonstrates, that trend has been reversing at current RGGI prices.

[4] In addition to RGGI, other technological, policy, and market drivers have also contributed to CO2 emission reductions over the past 15 years. These include, for example, other environmental policies, such as Renewable Portfolio Standards, and the declining costs of renewable technologies.

FIGURE 3

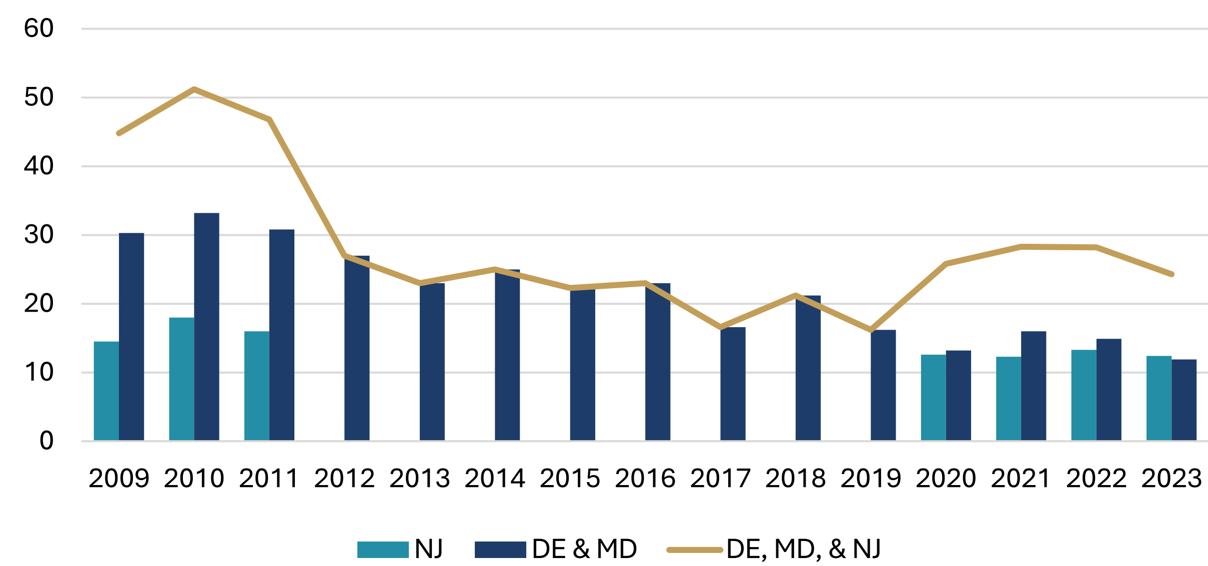
CO2 Emissions in RGGI States, 2009 to 2023 (Million Short Tons)



Notes: From 2009 – 2023, New Jersey participated in RGGI from 2009 through 2011 and again from 2020 to the present. RGGI reports statistics as “RGGI 10” when including New Jersey and as “RGGI 9” when excluding New Jersey.

FIGURE 4

CO2 Emissions in Delaware, Maryland, & New Jersey, 2009 to 2023 (Million Short Tons)



Notes: From 2009 – 2023, New Jersey participated in RGGI from 2009 through 2011 and again from 2020 to the present. RGGI reports statistics as “RGGI 10” when including New Jersey and as “RGGI 9” when excluding New Jersey.

2. Methodology for Quantitative Analysis

The quantitative analysis is based on power market simulations performed by TCR using the ENELYTIX modeling platform and the PJM model dataset maintained by TCR.

For the purpose of this study, TCR developed two simulation scenarios – the Business as Usual (BAU) Case and the No RGGI Case. Both scenarios cover a one-year time period from January 1, 2025 through December 31, 2025. The BAU Case represents the PJM market outlook assuming the states of Delaware, Maryland, and New Jersey continue to participate in RGGI. The No RGGI Case deviates from the BAU Case in one and only one assumption – setting the RGGI allowance price to zero, as if the RGGI CO2 emissions cap were no longer applied to the electric energy generation anywhere within the PJM footprint.

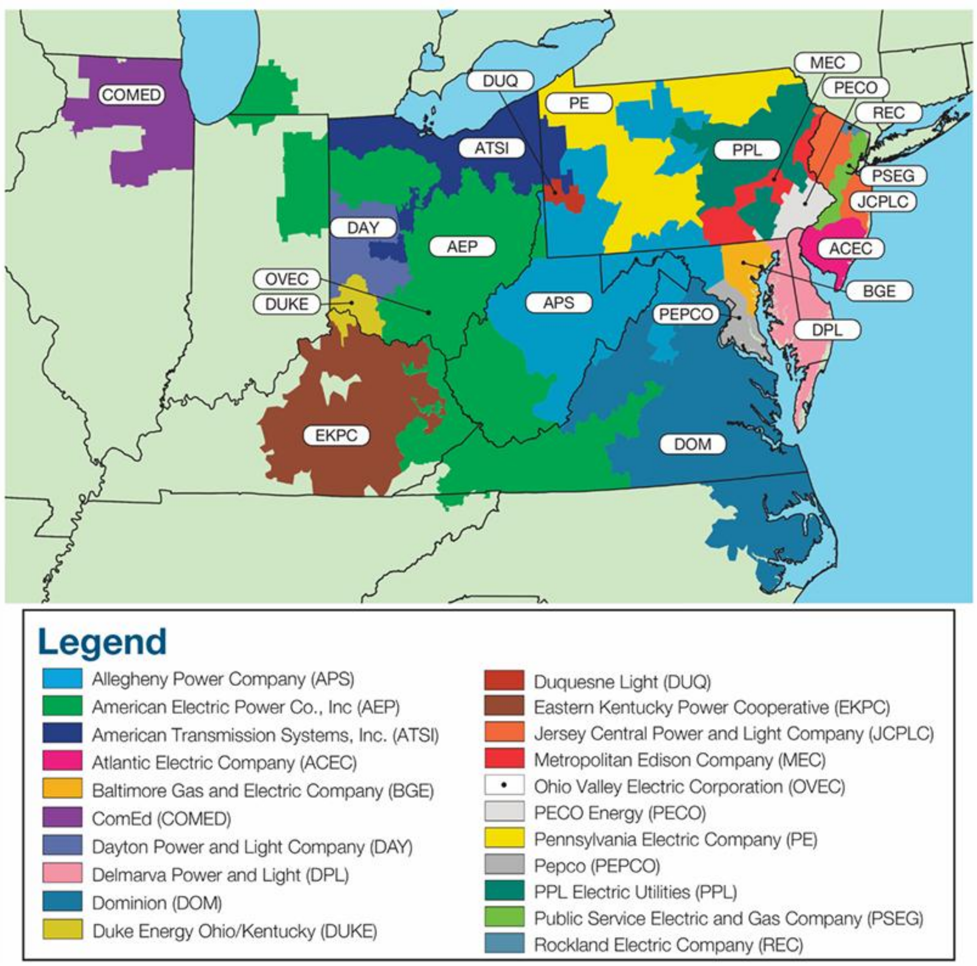
Under both cases, dispatch of generators in PJM was chronologically simulated with an hourly time step. TCR then compared the results of these two simulations, specifically focusing on the differences in Locational Marginal Prices (LMPs), wholesale load payments, generation levels, generator revenues, and CO2 emissions by technology type and PJM zone. These results are presented in Section 4.

3. The Base Case and Change Case

3.1. The Model Footprint

The geographic footprint modeled in this analysis includes all PJM market zones shown in Figure 5. The ENELYTIX model includes the physical representation of the electrical network of PJM and neighboring systems. The system includes an engineering economic model of power generating units, electricity demand, and their respective locations on the PJM network. The key engineering and economic parameters of these supply, demand, and transmission objects are defined within the dataset TCR maintains for all project studies the company undertakes.

FIGURE 5
PJM Footprint and Control Areas



Source: Monitoring Analytics

3.2. Key Model Inputs

TCR's PJM model is frequently updated to reflect the changing market conditions and new information related to categories such as:

- on-going changes in generation fleet (new additions, plants under construction, generator retirement or repowering decisions);
- transmission topology;
- electricity demand forecasts; and
- market outlook for fuel and RGGI allowance prices.

Using industry information, TCR updated its outlook on the state of the PJM electrical system as of the end of May 2024 and used PJM's most current load forecast available at that time. Similarly, TCR used forward curves for burner-tip natural gas and fuel oil prices from May 2024. This analysis uses an assumed RGGI allowance price of $20 per short ton of CO2 emitted. All prices are in real 2024 dollars. The past six months have shown no material changes in market curves or load assumptions for 2025. We would, therefore, expect no material changes in results were the assumptions to be updated.

As stated above, the only difference between the BAU Case and the No RGGI Case is the CO2 allowance price applied to thermal generators in Delaware, Maryland, and New Jersey.[5] The key effect of that assumption is to alter the operating rates (dispatch cost) of affected units.[6]

The change in operating rates is calculated internally by the Power System Optimizer (PSO), the market simulation engine within ENELYTIX.[7] For each affected generating unit, that change equals the product of the incremental emission rate per MWh of the unit at the specific operating point and the change in the carbon price. As an example, given the $20 per short ton CO2 price:

- a coal-fired power plant in a RGGI state with an emission rate of 1 short ton per MWh would see a reduction in operating rate of $20/MWh under the No RGGI Case;

- a typical gas-fired peaking plant in a RGGI state with an emission rate of 0.6 short ton per MWh would see a reduction of $12/MWh; and

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[5] Physical location is established in accordance with the EIA Form 860 data.

[6] Operating rate is equal to the incremental operating cost per MWh, including non-fuel VOM, incremental fuel cost and incremental emission allowance cost per MWh.

[7] See Appendix for more detail.

- a gas-fired combined-cycle power plant in a RGGI state with an emission rate of 0.4 short ton per MWh would see a reduction of $8/MWh.

These changes in the operating rates of affected power plants will change their position in the dispatch order and result in different generation, power flow, emissions, and price patterns within the PJM system.

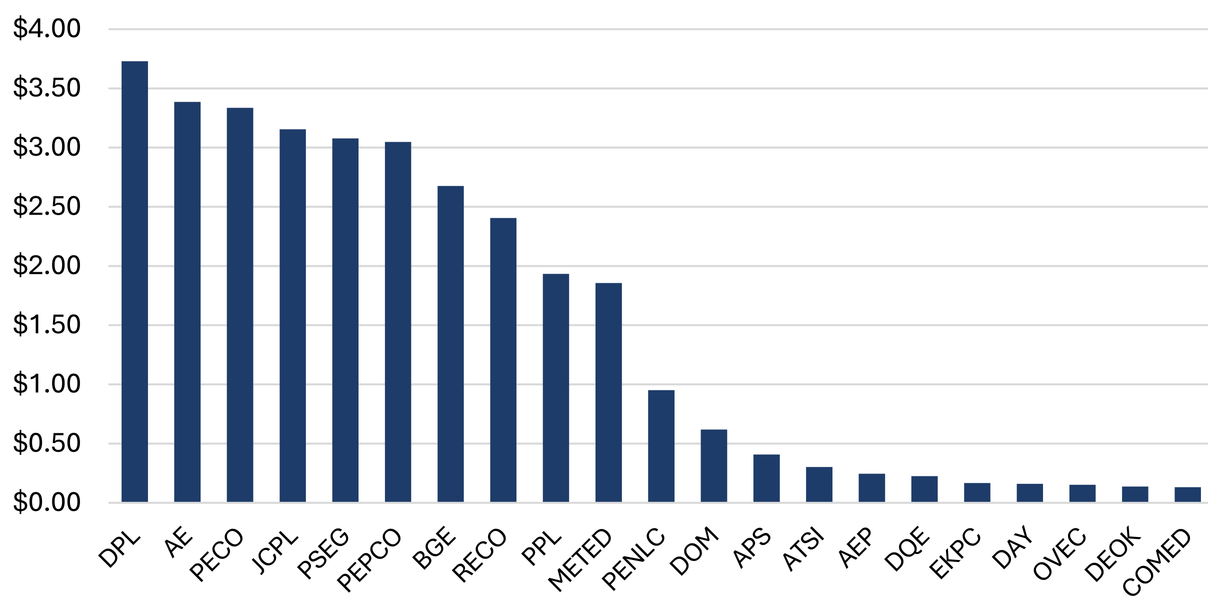
4. Modeling Results

4.1. Impact on LMPs and Load Payments

Delaware, Maryland, and New Jersey's participation in RGGI causes wholesale energy prices to increase in all parts of the PJM footprint. As shown in Figure 6, the annual average LMP increases in all PJM zones in the BAU Case compared to the No RGGI Case. The difference is most significant in the eastern and northeastern portions of PJM, where prices increase on the order of $2 - $3.75/MWh. Smaller price increases affect zones in western and southern PJM. These are under $0.5/MWh, but are still meaningful.

FIGURE 6

Impact of RGGI on Load LMPs, by Zone ($/MWh)

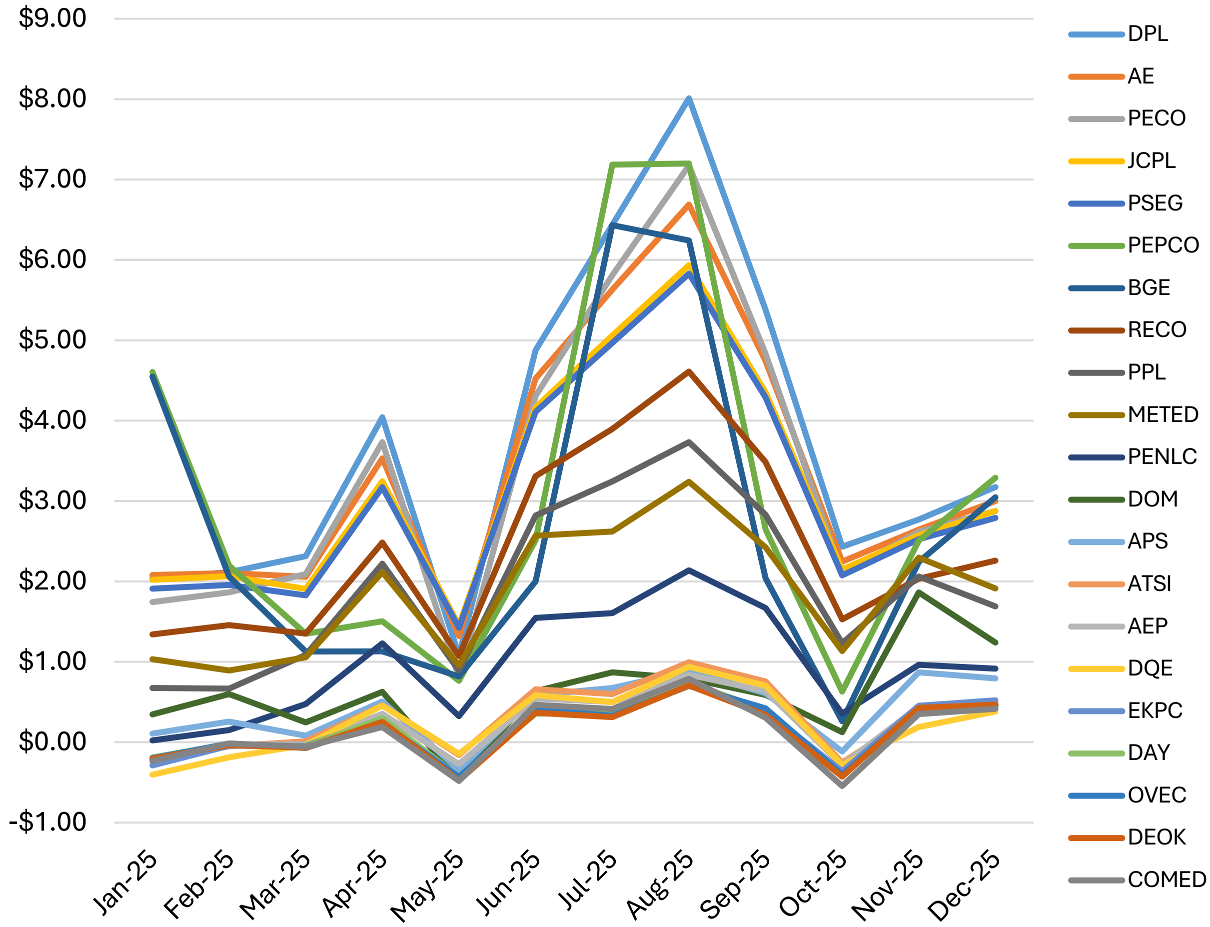


Notes: Value shown is the increase in LMP between the No RGGI Case and the BAU Case.

The price impact is not evenly spread across time but rather has the greatest impact during the summer peak season, when zones in eastern and northeastern PJM see monthly price increases due to RGGI as high as $8/MWh, as shown in Figure 7.

FIGURE 7

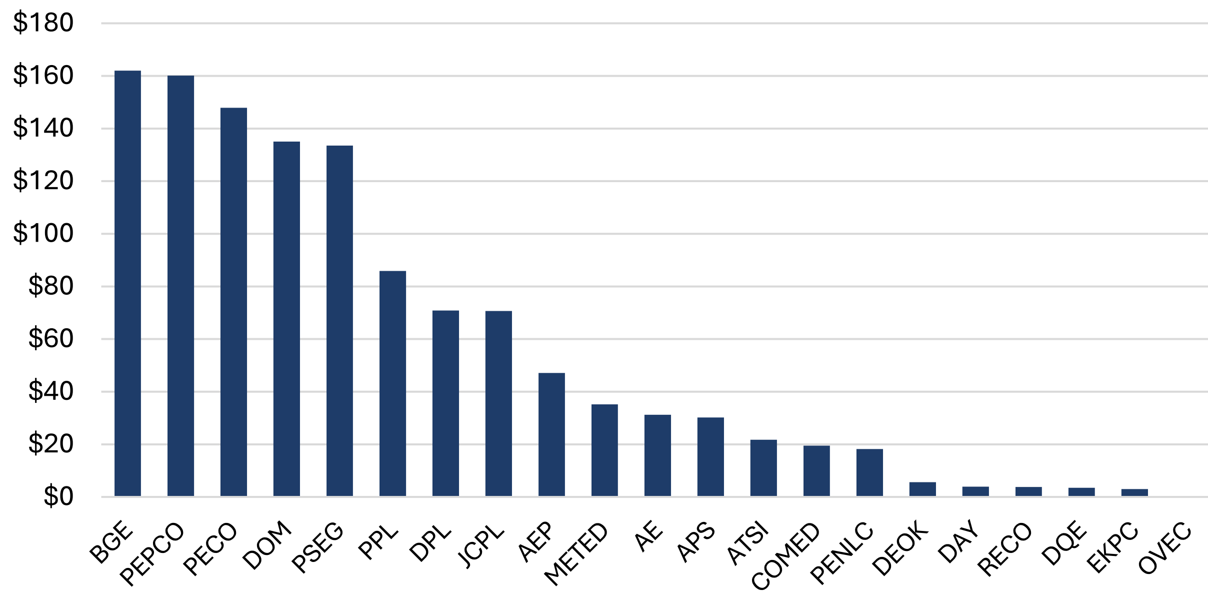
Impact of RGGI on Load LMPs, by Zone and Month ($/MWh)



Notes: Value shown is the increase in LMP between the No RGGI Case and the BAU Case.

The impact of RGGI on wholesale prices ultimately translates into costs payable by PJM consumers. That impact is shown graphically in Figure 8. The total cost to all PJM consumers is estimated to increase by $1.2 billion per year as a result of RGGI.

FIGURE 8
Impact of RGGI on Cost to Serve Load, by Zone ($M)



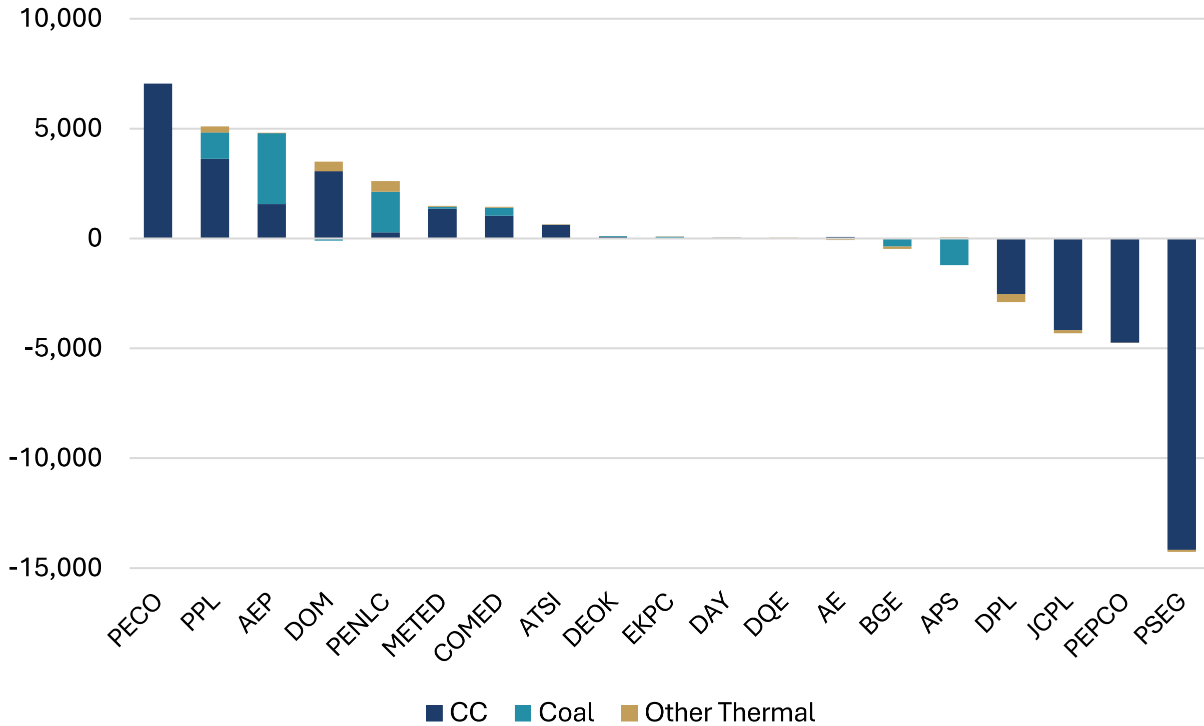
Notes: Value shown is the increase in cost to serve load between the No RGGI Case and the BAU Case.

4.2. Impact on Generation and Generator Revenues

Participation in RGGI predominantly affects the merit order and dispatch patterns of four generating technologies – coal-fired Steam Turbine units (“Coal”), gas-fired Combined Cycle units (“CC”), and other thermal technologies including gas- and oil-fired Steam Turbine units and gas- and oil-fired Internal Combustion or Gas Turbine units, which are referred to collectively in the charts as “Other Thermal”. The net effect on generation by technology within each PJM Zone is shown graphically in Figure 9. RGGI predominantly reduces gas-fired CC generation in eastern PJM which is replaced by generation in western zones, with a significant portion of that replacement generation being Coal units with high CO2 emission rates.

FIGURE 9

Impact of RGGI on Generation, by Zone (GWh)

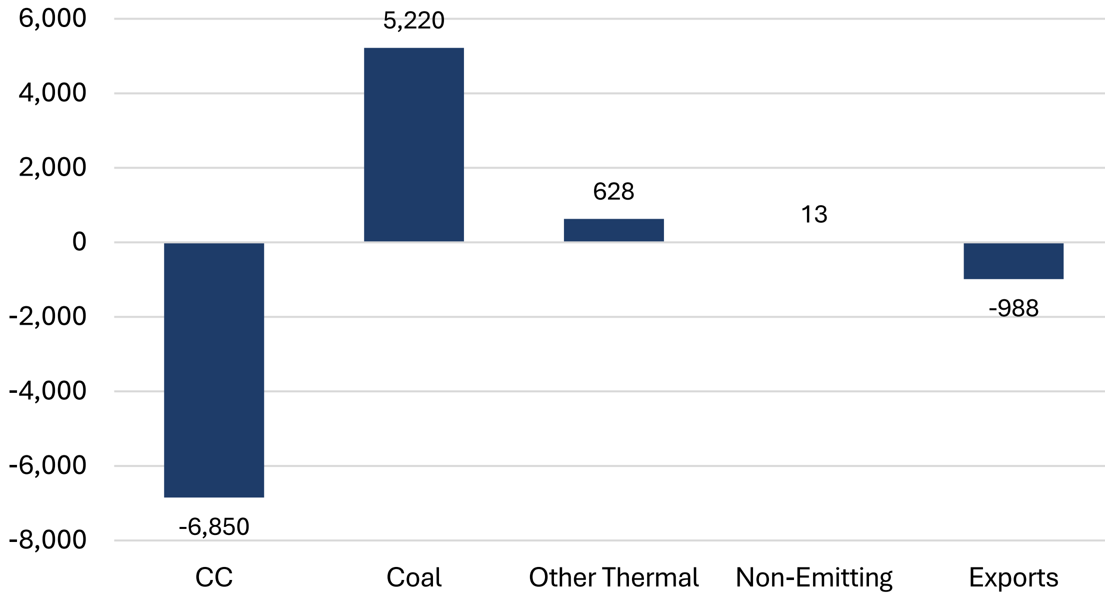


Notes: Value shown is the increase (decrease) in generation between the No RGGI Case and the BAU Case.

The PJM-wide change in generation resulting from RGGI is presented in Figure 10. Due to RGGI, total generation from efficient and low-emitting CC units is reduced by 6,850 GWh and replaced by 5,220 GWh of high-emitting Coal generation and 628 GWh of Other Thermal generation, resulting in the reduction of PJM energy exports to MISO of 988 GWh.

FIGURE 10

Impact of RGGI on PJM System-Wide Generation (GWh)

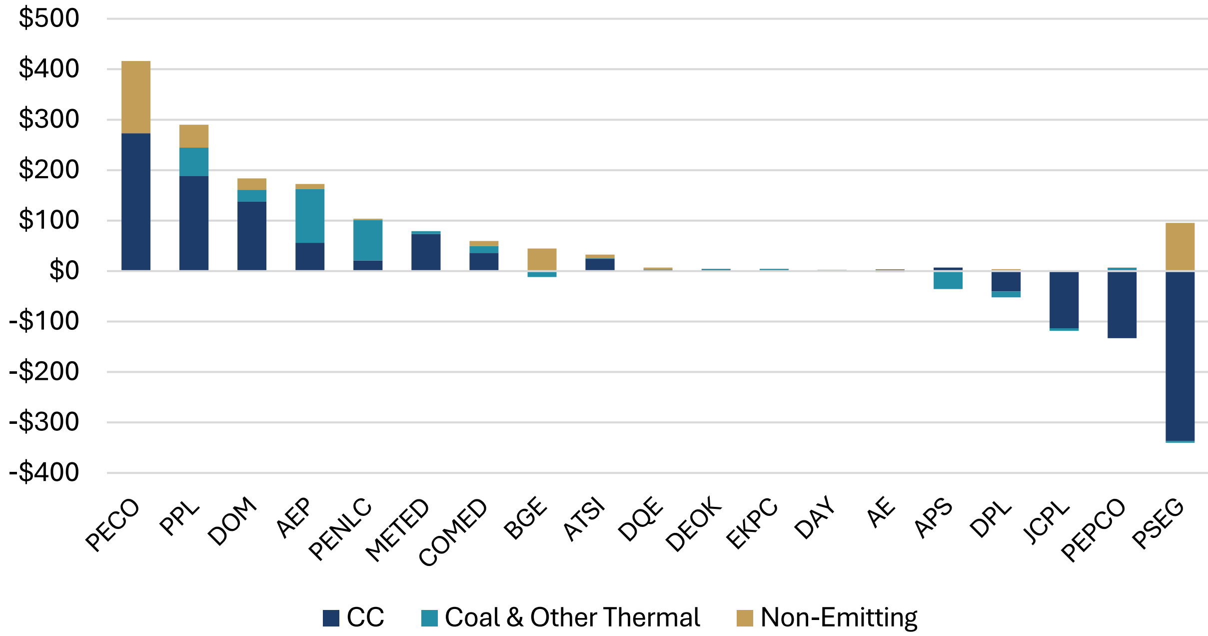


Notes: Value shown is the increase (decrease) in generation between the No RGGI Case and the BAU Case.

Corresponding to the impact on LMPs and generation is the impact on generator revenues, which is presented graphically in Figure 11. Generators in non RGGI participating states (in particular, Coal units in AEP, PPL, and PENLC, as well as non-emitting units throughout PJM) benefit from the allowance costs imposed on generators in RGGI states. Generating units located outside the RGGI participating states receive an overall annual increase in revenue amounting to nearly $1.3 billion. Meanwhile, generators in participating states see their annual revenue reduced by $0.5 billion, resulting in an $825 million net increase in generators' revenues over the study year for the entire PJM footprint.

FIGURE 11

Impact of RGGI on Generator Revenues, by Zone ($M)



Notes: Value shown is the increase (decrease) in generator revenues between the No RGGI Case and the BAU Case.

4.3. Impact on Carbon Emissions

The most dramatic observation resulting from our analysis is the increase in PJM system-wide CO2 emissions caused by Delaware, Maryland, and New Jersey's participation in RGGI. TCR estimates that the net annual impact of RGGI on CO2 emissions in PJM amounts to an increase of 2.7 million short tons.

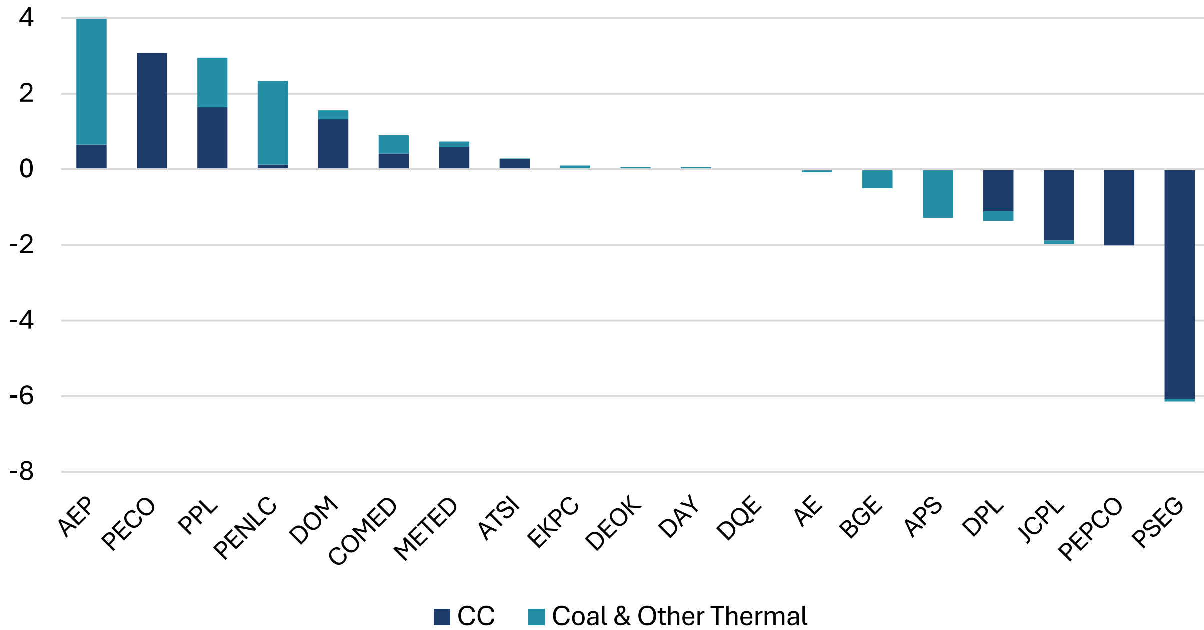
This effect is a direct result of RGGI's impact on the merit order of generating units in PJM, as discussed in the previous section. RGGI depresses generation by more efficient and lower CO2 emitting gas-fired CC generation in RGGI participating states and replaces that generation with less efficient coal-fired and higher CO2 emitting generation in other parts of the system.

Overall, the reduction in CO2 emissions by disadvantaged CC generators in the RGGI participating states amounts to approximately 3 million short tons, whereas CO2 emissions in other parts of PJM increase by 5.7 million short tons even though RGGI depresses the total generation in PJM and reduces power exports by nearly 1 TWh, which is likely causing further emission increases in MISO and other neighboring systems.

The impact on CO2 emissions in each PJM zone is shown in Figure 12. As the figure shows, emissions increase predominantly in the AEP, PECO, PPL PENLC, DOM, COMED, and METED zones. These increases exceed the emission reductions achieved by RGGI in the eastern zones of BGE, DPL, JCPL, PEPCO, and PSEG.

FIGURE 12

Impact of RGGI on CO2 Emissions, by Zone (Million Short Tons)



Notes: Value shown is the increase (decrease) in CO2 emissions between the No RGGI Case and the BAU Case.

4.4. The Bottom Line

While in the past RGGI has had a positive impact on the reduction of CO2 in PJM, that impact has now moved from a reduction in CO2 to one of an increase in CO2 along with a significant increase in cost to consumers in PJM. Our analysis indicates that emission reductions across the entire PJM footprint would, today, be even greater if RGGI were not implemented in any PJM state. Moreover, costs to PJM consumers would also decrease were RGGI not implemented in any PJM state. RGGI appears, quite clearly, to have outlived its stated objective in PJM and from a policy perspective is in need of significant realignment if not elimination.

Appendix

ENELYTIX® Powered by PSO

ENELYTIX® is a Software as a Service (SaaS) energy market simulation environment implemented on Amazon EC2, a commercial cloud computing platform.[8]

A central element of ENELYTIX is the Power System Optimizer (PSO), an advanced power markets simulator.[9] PSO provides ENELYTIX the capability to accurately model the decision processes used in a wide range of power planning and market structures including long-term system expansion, capacity markets, Day-Ahead (DA) energy markets, and Real-Time (RT) energy markets. ENELYTIX has this capability because it can configure PSO to determine the optimum solution to each market structure.

As a system expansion optimization model, PSO integrates resource adequacy requirements and the specific design of the capacity market with environmental compliance policies, such as state-level and regional Renewable Portfolio Standards (RPS) and emission constraints.

As a production cost model, PSO is built on a Mixed Integer Programming (MIP) unit commitment and economic dispatch structure that simulates the operation of the electric power system. PSO determines the security-constrained commitment and dispatch of each modeled generating unit, the loading of each element of the transmission system, and the locational marginal price (LMP) for each generator and load area. PSO supports both hourly and sub-hourly timescales.

For this analysis, PSO was set up to model unit commitment (DA market) and economic dispatch (RT market). In the commitment process, generating units in a region are turned on or kept on in order for the system to have enough generating capacity available to meet the expected next-day peak load and operating reserve requirements. PSO then uses the set of committed units to dispatch the system on an hourly real-time basis, whereby committed units throughout the modeled footprint are operated between their minimum and maximum operating points to minimize total production costs. The unit commitment in PSO is formulated as a mixed integer linear programming optimization problem, which is solved to the true optima using the commercial CPLEX solver.[10]

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[8] ENELYTIX® is a registered trademark of Newton Energy Group, LLC.

[9] PSO is a product of Polaris System Optimization, Inc.

[10] CPLEX is a product of IBM Corporation.

The ENELYTIX/PSO modeling environment provides a realistic, objective, and highly defendable analysis of the physical and financial performance of power systems, in particular power systems integrating variable renewable resources. The critical advantage of ENELYTIX/PSO over traditional production costing modeling tools is its ability to model the concurrent dynamics of:

1. uncertainty of future conditions of the power system;

2. the scope, physical capabilities, and economics of options available to the system operator to respond to these uncertain conditions;

3. the timing and optionality or irreversibility of the operator's decisions to exercise these options.

By capturing these concurrent dynamics, ENELYTIX/PSO avoids the generally recognized inability of traditional simulation tools to reflect the effect of operational decisions on the physics of the power system, price formation, and financial performance of physical and financial assets.

For additional information about ENELYTIX powered by PSO, visit https://enelytix.com.