MISO/PJM Joint Modeling

Case Study: Clean Power Analysis

MISO
PJM Interconnection
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Executive Summary

When it was introduced, the U.S. Environmental Protection Agency's (EPA) Clean Power Plan (CPP) for regulating carbon dioxide emissions from the electric power sector was widely recognized to have a potential transformative impact on the sources of power supply. By request of their states and stakeholders, MISO and PJM previously analyzed the CPP independently in order to provide their state agencies with objective analysis they could consider in developing CPP compliance plans.

Since its introduction as a proposed rule, the CPP has garnered a significant amount of opposition, and the current political environment makes it unlikely that it will survive in its current form. The CPP, while controversial, is only one of many policy and market drivers that states are faced with as they think about current and future electric supply.

As a follow-up to their initial studies, MISO and PJM both saw a benefit to conducting an additional joint policy evaluation using the CPP as a case study. The MISO and PJM footprints are adjacent and share a significant electrical seam. The various ways in which states could have developed compliance plans with the CPP could add additional complexity to operating generation and transmission; thus, the CPP provides a good stress test to illustrate not only the value of interregional coordination but state coordination as new policies and/or regulations are considered.

The observations in this report are **not** recommendations for complying with the CPP. However, states, utilities and other entities can consider the observations made from this analysis within the specific context of the CPP or in a broader context as they consider other policy goals that can influence already dynamic economic interactions in electric markets.

Study focus and key observations

MISO and PJM coordinated on an interregional assessment of the impact of environmental regulations and policy on grid operations. They considered economic interchange, congestion on the transmission system, utilization of generation resource types, generation production costs and energy market costs. They examined the effects of external drivers such as the price of natural gas, the effects of varying the size of the emissions trading region and the effects of using energy efficiency as a compliance mechanism.

From this analysis, they made the following key observations:

- External economic drivers may overshadow state policy choices. Natural gas prices heavily influence the cost and impact of state policy objectives by influencing resource economics (zero-emitting project viability).
- Standardization of state policy decisions may reduce associated program costs. Standardization of energy efficiency measurement and verification facilitates commoditization of credits across broader markets; and would enhance energy efficiency's value to consumers by offsetting deployment costs.

- Disconnected state policies can drive significant economic distortions along the seam and exacerbate transmission cost impacts. The ability to transact fungible products among states results in greater market efficiency, both within individual states and across the PJM and MISO footprints.

Clean Power Plan Summary

On August 3, 2015, the U.S. Environmental Protection Agency (EPA) released its Final Clean Power Plan rule to regulate carbon dioxide (CO_2) emissions under section 111(d) of the Clean Air Act. The rule applies to existing and under-construction fossil fuel electric generating units satisfying EPA's eligibility criteria. EPA developed what it considers to be the "best system of emissions reductions" to develop interim and final compliance rate-based performance standards to be achieved by states and/or affected generating units within those states. The EPA also provided state-level mass targets intended to represent an equivalent amount of emissions reductions as anticipated under the rate-based standard. Nationwide the regulation intends to reduce total CO_2 emissions from eligible sources by 32 percent by 2030 relative to 2005 levels.

In addition to section 111(d) of the Clean Air Act, the EPA established performance standards for new, modified and reconstructed sources (New Source Performance Standards) under section 111(b) of the Clean Air Act. The New Source Performance Standards are based on emissions performance achievable by individual generating units.

Both regulations face implementation uncertainty due to pending legal challenges, as well as potential policy changes by the current Presidential administration. If implemented, the combination of these rules potentially will influence the way energy is produced and delivered within the PJM and MISO footprint, and influence future investments in generation sources.

PJM and MISO's role as regional transmission organizations (RTO) is to ensure cost-effective delivery of generation over the bulk transmission system. PJM and MISO both serve wholesale load and dispatch generation in the states of Michigan, Illinois, Indiana, Kentucky. PJM and MISO do not coordinate to ensure resource adequacy and do not develop generation expansions plans; however, both coordinate to ensure operational reliability through their energy markets and long-term transmission security through their respective transmission expansion planning processes.

Analysis

Background and Study Objectives

The seam connecting MISO and PJM runs within Michigan, Illinois, Indiana, Kentucky and along the borders of other states, and consists of many transmission elements operated at various voltage levels. The MISO/PJM seam presents operational challenges, namely coordinating interchange and transmission constraint mitigation, and longer-term challenges in planning new transmission. Regardless of the ultimate outcome of the Clean Power Plan (CPP) and national carbon regulation generally, PJM and MISO find value in performing joint modeling and analysis. The CPP is a useful case study to better understand and share observations about the impacts of environmental regulations and policy on grid operations, particularly across an electrical operating seam such as the one between PJM and MISO. Furthermore, the joint effort allows MISO and PJM to build joint technical capabilities and relationships beneficial to future joint work.

This coordinated analysis is built off the studies MISO and PJM individually performed for their respective systems and leverages lessons learned from those analyses. It utilizes the most relevant information and features from the individual studies, along with a common set of assumptions and a common modeling tool.

States, through their emissions compliance decisions, can facilitate broader trading to mitigate potential uncertainty in the operation of the transmission and generation along the seam. In this study, MISO and PJM assess the impact of broader emissions trading on generation resources and transmission utilization in both markets. States can also coordinate the measurement and verification of energy efficiency, which can be a key resource in facilitating compliance. In this study, MISO and PJM also evaluate the impact of this coordination effort.

The joint analysis conducted by PJM and MISO represents a case study and will not be used to identify transmission upgrades for inclusion into either RTO's future transmission expansion plan. The analysis is scenario-based and focused on potential economic, operational and transmission usage conditions within the PJM and MISO footprint.

Model Development

Both PJM's and MISO's previous analyses found that regional trading resulted in lower cost to comply with the CPP than state-only compliance. The potential for more challenging operational conditions to arise under disparate compliance approaches is greater between independent RTO systems than it is between states within the same RTO. Between RTOs, economic substitution of resources is less efficient because each RTO dispatches generation resources using independent market clearing systems and there are transaction costs between market regions.

The CPP could add complexity because resources within the same state could potentially participate in one emissions trading market while operating in different power markets.[1] The CPP, therefore, has the potential to

[1] Initial analysis assumed that resources within each state adopt the same approach as other resources located in the same RTO.

exacerbate market price differences between regions, which could drive different interchange patterns and transmission developments than without the CPP.

To examine these effects, several scenarios were developed and evaluated under joint coordinated analysis. The following sections detail the assumptions of these scenarios.

MISO Resource Expansion

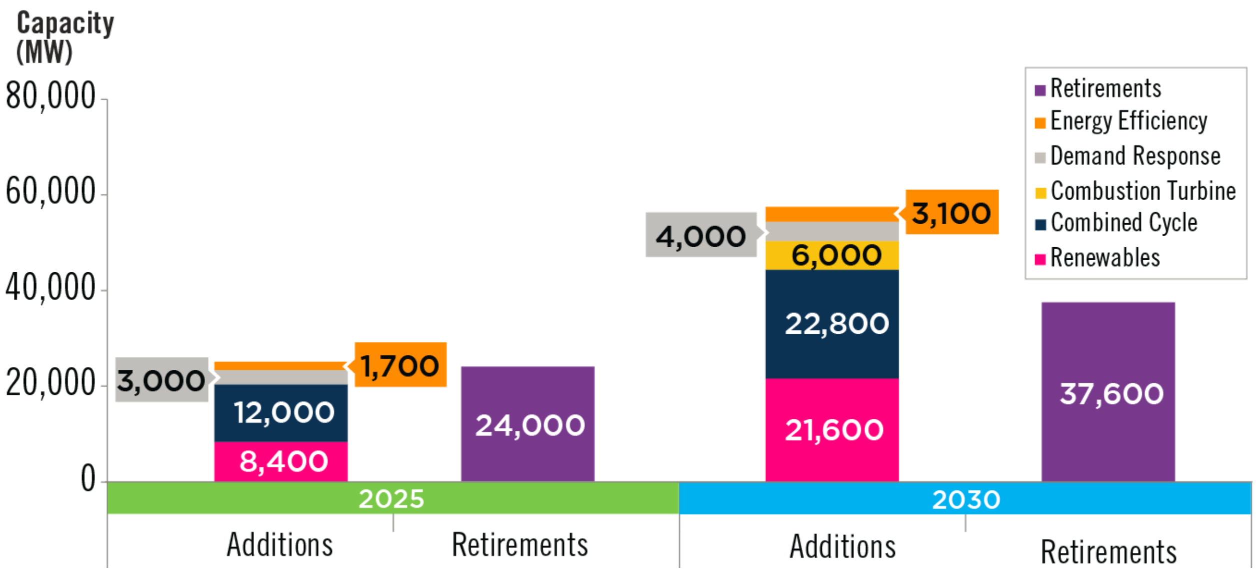
The base dataset for MISO's generation fleet was the 2017 MISO Transmission Expansion Plan (MTEP17) Policy Regulation (PR) economic study model. The PR future assumes carbon regulations that target a 25 percent reduction in CO_2 emissions from 2005 levels from all CO_2-emitting units by 2031. This drives coal retirements and an increase in natural gas reliance. Increased renewable additions are driven by renewable portfolio standards and goals, economics and business practices to meet carbon regulations.

MISO's generation interconnection queue is the primary source for out-year capacity; however, the queue is generally limited to five years out or less for new capacity. The Electric Generation Expansion Analysis System (EGEAS), created by the Electric Power Research Institute, is the capacity expansion software tool used by MISO for long-term regional resource forecasting. EGEAS performs a capacity expansion to indicate when and what type of resources could be added to the system. EGEAS does this using an objective function that aims to minimize the 20-year capital and production costs while maintaining load-to-resource balance and a planning reserve margin requirement.

The generation forecast EGEAS produced in the PR future was used for MISO's generation mix in this study. Figure 1 illustrates the cumulative changes in MISO's generation fleet. These changes also include coal and gas/oil steam turbine retirements of 24 GW by 2025 and 37.6 GW by 2030, levels identified from the results of MISO's mid-term CPP Analysis[2]. These retirements are mainly due to age and policy related assumptions.

[2] https://www.misoenergy.org/_layouts/MISO/ECM/Redirect.aspx?ID=229189

Figure 1. MISO cumulative resource additions and retirements



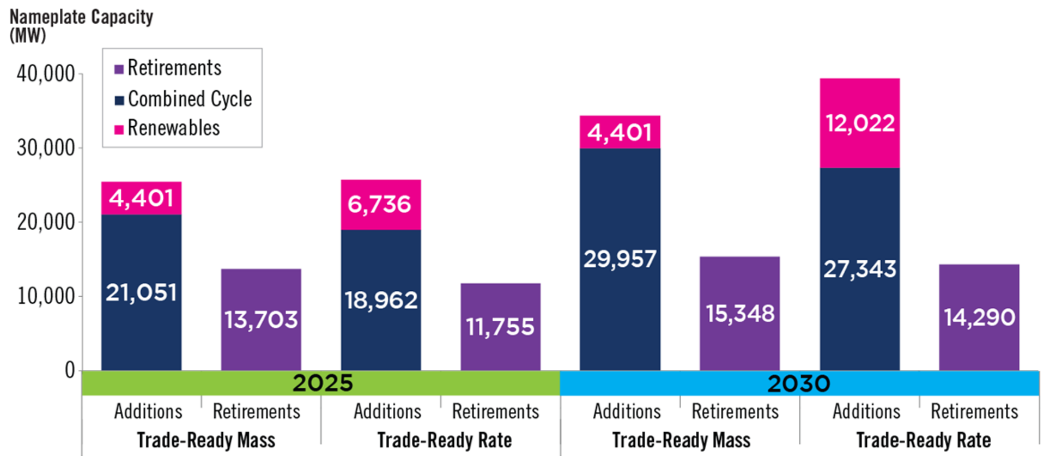
PJM Resource Expansion

For the joint study, PJM utilized the resource portfolios developed from its earlier evaluation of trade-ready mass and trade-ready rate-based compliance under the final Clean Power Plan. For additional information on the methodology and inputs for this analysis see PJM's CPP Compliance Assessment. Trade-ready mass-based compliance, which does not by default provide direct economic incentives for renewable resources, led to natural gas combined cycles being the primary replacement option for retiring coal resources. Trade-ready rate-based compliance did directly credit renewable resources for their energy production, and resulted in higher levels of wind and solar resources entering the PJM market[3], especially by 2030, when the EPA's CO_2 emissions targets reach their lowest levels.

For joint analysis, PJM used both its mass-based resource mix and rate-based resource mix. Throughout this assessment, the resource mix based on a trade-ready mass policy future is referred to as the "lower renewable" future whereas the resource mix derived from PJM's analysis of a trade-ready rate policy future is referred to as the "higher renewable" future.

[3] Higher generator additions ae observed by 2025 due to a combination of economic retirements occurring earlier in PJM's CPP Compliance Assessment study, but also because of already planned additions at the advance stages of the development process.

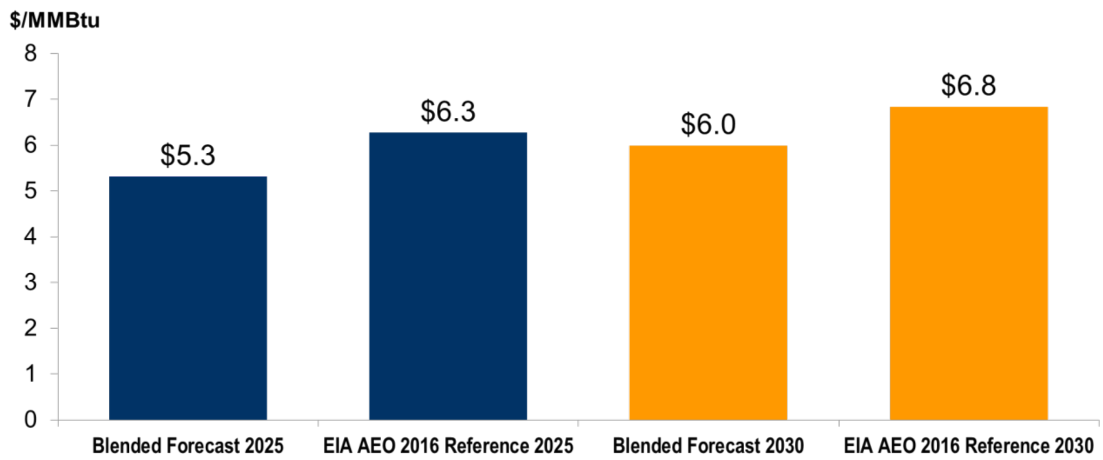
Figure 2. PJM cumulative resource additions and retirements



Natural Gas Prices

In both MISO's and PJM's independent analyses, natural gas prices played a significant role in the assessment of CPP's economic impacts. MISO and PJM used different natural gas price assumptions in their independent analyses but agreed to use common fuel prices for the joint analysis. MISO and PJM used a blend of the "EIA 2016 Annual Energy Outlook" and "IHS CERA Monthly Natural Gas Briefing" for the base set of scenarios. The annual average price is represented by the orange bars in Figure 3.

Figure 3. Natural gas nominal Henry Hub forecast prices



The blue bars in Figure 3 illustrate the average Henry Hub price in nominal dollars from the "EIA's 2016 Annual Energy Outlook" and were used for sensitivity analysis.

Modeling CO_2 Emissions Compliance

Mass-Based Compliance

Mass-based compliance employs an explicit cap on the emissions from affected sources. Compliance with mass-based emissions targets is achieved by each of the affected sources holding emissions allowances[4] sufficient to cover CO_2 emissions recorded by the affected source's continuous emissions monitoring system at the end of each compliance period.

The modeling implicitly reflects an auction structure in which generators are able to purchase allowances through either a multi-state (e.g. RTO) framework, in which trading is limited to resources physically in the same region or with no limitations on trading of CO_2 allowances. The clearing price in the model represents the marginal costs of abatement[5] required to not exceed the emissions limitation. For additional information on the allowances available in the PJM and MISO region, see the Environmental Protection Agency's technical support document on unit-level allowance allocations[6] by compliance period.[7]

Rate-Based Compliance

In contrast to a mass-based limit on overall emissions, rate-based compliance does not cap overall tons of emissions. Instead, a rate-based compliance pathway mandates that affected resources must achieve a target emissions rate in pounds of CO_2 per megawatt-hour of energy produced (lbs. CO_2/MWh). Under the compliance pathways proposed by the EPA, affected resources could increase their generating efficiency to achieve the mandated emissions rate standard or affected sources could buy emission rate credits from other sources. Similar to allowances, emissions rate credits (ERCs) are tradable commodities to enable CO_2-emitting resources to achieve compliance with the rate standard.

Qualifying low- or zero-emitting resources generate ERCs when they generate energy (megawatt-hours). While there is not an explicit cap on emissions under rate-based compliance, the total amount of ERCs in circulation during a compliance period may limit the amount of emissions that can be produced on a mass (tons) basis – the supply of

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[4] Holders of emission allowances can emit one short ton (2,000 pounds) of CO_2 for every allowance they possess.

[5] In general, the marginal cost of abatement is a determined by the cost of re-dispatching a more expensive and cleaner source, such as combined cycle natural gas, to displace a less expensive but higher-emitting source such a coal or oil steam.

[6] Data file: Appendix A: Allocations and Underlying Data (xlsx) https://www.epa.gov/sites/production/files/2015-11/documents/tsd-fp-allowance-allocations.pdf

[7] See Clean Power Plan, Section VIII State Plans, subsection D State Plan Components and Approvability Criteria at 64,849. Compliance periods for the Clean Power Plan are initially three-year periods, 2022-2024 and 2025-2027, and then in two-year periods thereafter 2028-2029, 2030-2031, etc.

ERCs must at-least match demand for ERCs. The clearing price for ERCs represents the marginal cost for the supply/demand constraint.[8]

Base Case Scenarios and Sensitivities

This case study used two separate base cases to evaluate compliance with either mass-based or rate-based CO_2 regulation. The choice of two base cases evolved from PJM's earlier analysis, which found that rate-based compliance led to higher levels of renewable resources. Consequently, any scenario in which PJM resources are studied as complying with a rate-based standard used the "higher renewable" base case.

Table 1. Base case scenario descriptions

Base Case	Description
Lower Renewable	• PJM's resource expansion developed under trade-ready mass-based compliance • MISO's resource expansion developed in MTEP17 Policy Regulation future • Blend of EIA 2016 Annual Energy Outlook & IHS CERA Monthly Natural Gas Briefing
Higher Renewable	• PJM's resource expansion developed under trade-ready rate-based compliance • MISO's resource expansion developed in MTEP17 Policy Regulation future • Blend of EIA 2016 Annual Energy Outlook & IHS CERA Monthly Natural Gas Briefing

Using the two base cases described above, PJM and MISO developed scenarios in which CO_2 regulations were enforced in each region shown in Table 2. PJM and MISO assessed the impact of their member states adopting the same compliance methods for all resources versus a patchwork approach.[9]

[8] In this analysis, the price can only be formed based on re-dispatch from higher-emitting sources to lower-emitting sources. In analysis that allows new entry, the price is also influenced by the incremental cost that must be recovered to incent new zero-emitting resources to enter the market.

[9] In this analysis patchwork approaches are characterized by resources in one RTO region complying through a rate-based standard, whereas resources in the other RTO comply with a mass-based standard.

Table 2. Emissions compliance scenarios studied with base case resource and fuel assumptions

Scenario	Base Case	MISO Trading Instrument	PJM Trading Instrument	Energy Efficiency Credit
PJM Rate MISO Mass	Higher Renewable	Allowance	Emission Rate Credit	None
PJM Mass MISO Rate	Lower Renewable	Emission Rate Credit	Allowance	None
Trade-Ready Rate	Higher Renewable	Emission Rate Credit	Emission Rate Credit	None
Trade-Ready Mass	Lower Renewable	Allowance	Allowance	Not Applicable

Trading of emissions credits or allowances was permitted in scenarios where MISO and PJM resources complied using the same trading instrument (i.e. ERCs or allowances). Notably, renewable resources were limited to generating ERCs only when they were located in the same physical ISO region as thermal resources also engaged in trading ERCs. Because mass-based and rate-based compliance represent two separate regulatory options, the patchwork scenarios were not intended to evaluate the relative economic benefits of broader trading regions versus more localized trading. Instead, their focus was to evaluate the economic impacts of the MISO or PJM region adopting a mass- or rate-based approach subject to the set of resources and fuel assumptions in the model.

Study Findings

Generation Impacts Analysis

The joint PJM and MISO case study is focused on operational impacts associated with states' adoption of various CO_2 emissions limitation options. Operational impacts consist of changes in generation dispatch in response to the CO_2 price. As generation dispatch changes, so do emissions levels and the cost of generator operations in the respective PJM and MISO system.

Previous analysis conducted by PJM and MISO showed that the economic effects driven by a particular regulation could vary significantly when looking at individual resources and/or collections of resources in particular states. An interconnected power system naturally provides more flexibility in complying with an emissions regulation, but also makes it more difficult to identify any single driver for the resulting interactions. Consequently, PJM and MISO determined that more insightful observations can be made for the collection of states by aggregating the operational and cost variables associated with generation in the PJM and MISO regions.

CO_2 Emissions Performance and CO_2 prices

As shown in Figure 4, the total amount of emissions varied across scenarios as a function of the emissions standard applied to PJM or MISO resources. This graph also includes the emissions prices for each scenario. Full trading between MISO and PJM occurs under the trade-ready rate-based and trade-ready mass-based scenarios and results in a common CO_2 price. Rate-based versus mass-based compliance uses a different commodity and thus results in two different emissions markets and CO_2 prices. [10]

Figure 4. Total CO_2 emissions and emissions prices in MISO and PJM

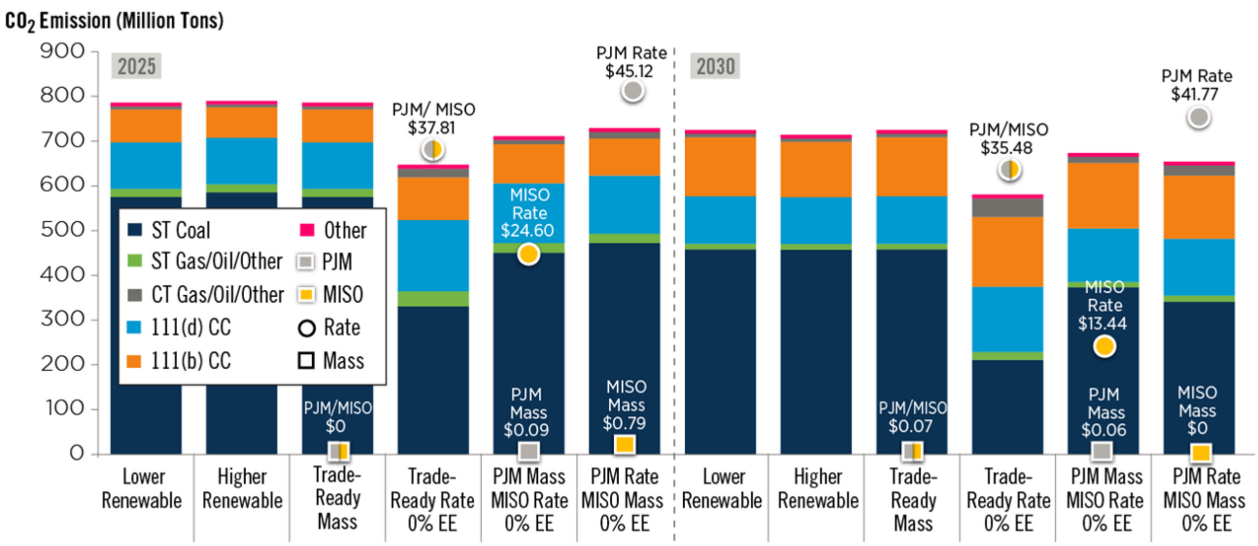


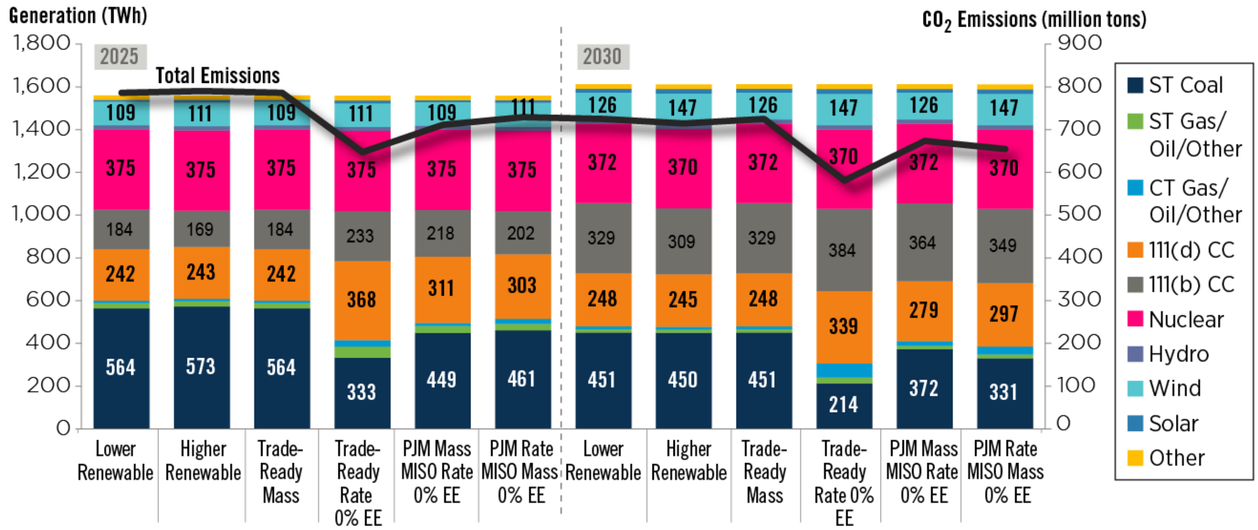
Figure 4 shows that emissions prices were lowest under the trade-ready mass-based scenario, where MISO and PJM states adopt a common policy for regulating CO_2 emissions. Patchwork implementations, which, by design, do not allow trading, will result in higher CO_2 prices for one or the other region. Figure 4 also shows that prices generally decreased between 2025 and 2030, despite the increasing stringency of the emission reduction targets. This is driven by the entry of new renewable resources in both ISOs and increases in energy efficiency deployed in both ISOs.

Generator Fuel Mix

Figure 5 illustrates the fuel mix by generation technology aggregated for the PJM and MISO regions. In addition, the solid black line shows the total emissions for the two regions.

[10] Within the PLEXOS optimization model, the CO_2 price is an output based on the model achieving supply and demand balance for ERCs or allowances.

Figure 5. Fuel Mix and Total CO_2 Emissions in the MISO and PJM Region



Mass-Based Allowance Trading Between PJM and MISO

Generator performance under trade-ready mass-based was the same as the base case (i.e. Lower Renewable) in 2025 because the CO_2 price required to enable resources to remain in compliance was zero. By 2030, because of resource retirements and additional entry of low or zero-emitting resources, the CO_2 price remained near zero, as shown in Figure 4. A very low CO_2 price, \$0.07/ton, under trade-ready mass-based did not effectuate significant changes in the generation dispatch. Consequently, the contribution of the various generation technologies to the total fuel mix remained the same relative to the base case.

Emissions Rate Credit Trading Between PJM and MISO

Under a rate-based policy implementation (i.e. trade-ready rate-based) , the limited supply of economic ERCs resulted in significant declines in coal generation offset by an increase in natural gas generation, both from regulated CCs and unregulated CCs[11]. Steam turbine (ST) gas units also fill some of the void created by declines in coal generation. By burning gas, these units have much lower emission production rates than their ST coal counterparts regulated under the same emission standard as coal units. Compared to combined cycle gas units, re-dispatch to ST gas is indicative of a higher clearing price for ERCs required for the systems to remain in compliance. The level of re-dispatch from coal to gas generation would be lower if the supply of ERCs associated with zero-emitting technologies was more plentiful.

Patchwork Approach

The patchwork approaches labelled “PJM Mass MISO Rate” and “PJM Rate MISO Mass” also resulted in significant re-dispatch from coal to gas generation but much less than the level resulting from states’ adoption of common ERC

[11] The EPA defines regulated resources are defined as steam turbine or combined cycle driven fossil fuel based generation that is installed or under-construction by November of 2014.

trading in the PJM and MISO footprint. This result can be explained by the CO_2 prices formed for MISO and PJM respectively under the patchwork scenarios. When resources in either RTO comply through trading allowances, the CO_2 price approaches $0/ton. However, adoption of a rate-based standard results in a much higher CO_2 price ranging from $13.44 to $45.12/ERC as shown in Figure 4. The significant drop in the MISO rate price between 2025 and 2030 relative to that observed for PJM over the same period can be attributed to the more significant growth in renewable resources added to the MISO footprint by 2030, as shown in Figure 1.[12]

The results from the analysis should not be interpreted as *mass-based compliance strategies will always produce the least amount of system impacts*. However, the results are clear that a future characterized by continuation of low gas prices favors mass-based approaches.

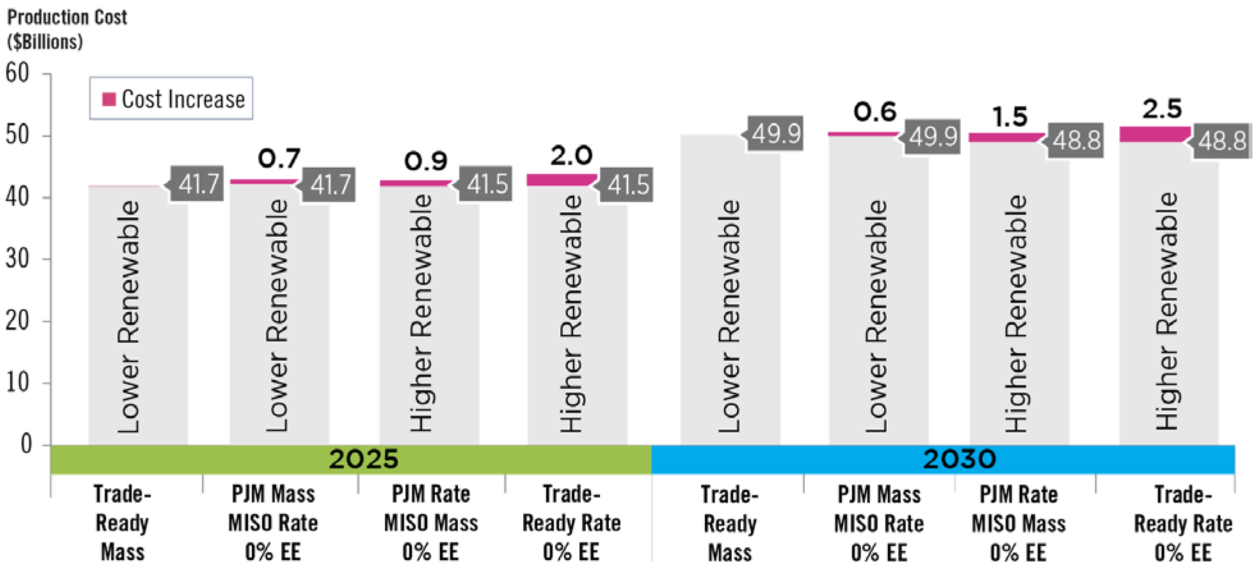
Generator Production Cost

Generator production costs[13] were also examined as part of the MISO and PJM coordinated analysis. Figure 6 shows the increase in generator production cost across the base case scenarios.

[12] MISO stakeholders may note that decreases in the CO_2 price over time was not observed in MISO's individual analysis. This is a product of how the resource optimization was performed. MISO's previous analysis was a scenario-based analysis using various user-defined resource portfolios developed to represent a wide array of compliance options; this current analysis used a resource fleet developed with emissions restrictions. The differences between the current analysis and previous analysis emphasize the importance of evaluating the effects of resource entry and exit in conjunction with operational measures of regulatory compliance for long-term planning.

[13] Generator production cost includes only direct cost to operate the generation (i.e. fuel, O&M, start-cost). The cost of allowances or ERCs is not captured in the production cost.

Figure 6. Increase in Production Costs in MISO and PJM



Consistent with observations made for unit operation, trade-ready mass compliance did not result in a substantive increase in operating cost relative to its base case (i.e. lower renewable) in either 2025 or 2030. A near-0 CO_2 price means that there was no meaningful shift in generation dispatch to achieve the emissions targets.

Patchwork approaches did lead to a positive compliance cost supported by a shift in the dispatch. The highest cost increase resulted from the trade-ready rate-based scenario. This result again is indicative of both systems economic preference for mass-based compliance given low gas prices and the low supply of ERCs contributed by energy efficiency and renewable resources.

Transmission and Market Pricing Impacts

The PJM and MISO systems are interconnected via a set of transmission lines that facilitate energy transfers between the regions. Typically, energy should flow from the system with the lowest cost marginal resources to the system with higher cost marginal resources. As the emissions policy changes, so does the relative cost of generation, which can impact both the level and direction of economic interchange transacted between PJM and MISO. Market prices are both a function of the marginal cost of generation, and loading on the transmission system. High loading of the transmission system translates into increased costs to operate generation and is known as transmission congestion. Depending on whether load is contributing to increased congestion or helping to mitigate it, locational marginal prices in the PJM and MISO region can go up or down.

Physical Flows between PJM and MISO: Interchange Transactions Assessment

MISO and PJM's coordinated analysis also examined the interchange levels between the two RTOs. In most cases, PJM is a net seller of energy to MISO as shown in Figure 7.

Figure 7. Net interchange between MISO and PJM

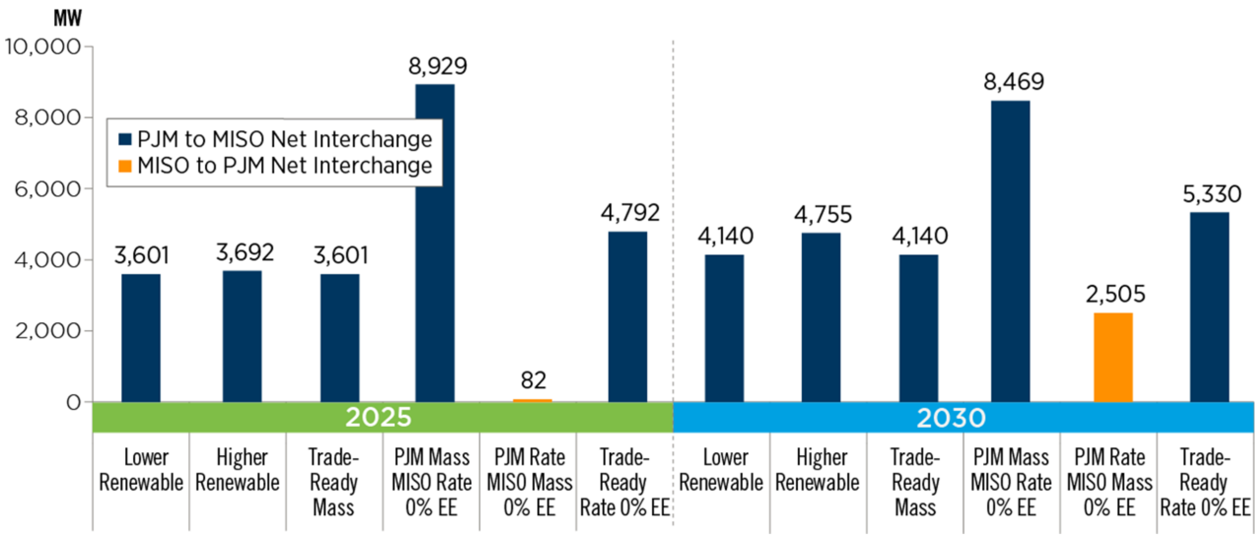


Figure 1 Net interchange between MISO and PJM

Over the last five years, the net scheduled interchange between PJM and MISO has oscillated between PJM being a net-seller to MISO and vice versa. By 2025 and 2030 however, changes in each system's resource mix (e.g. coal retirements, new combined cycle gas additions) resulted in PJM being a strong net-exporter of energy to MISO in all of the scenarios, except for the patchwork scenario in which PJM resources complied with a rate-based target.[14] Although both systems add a significant amount of combined cycle gas, PJM's resources are located much closer to shale formations and thus have a lower fuel delivery basis and lower operating cost than the MISO resources. Wind becomes even more prominent in MISO, however economic interchange occurs as a function of marginal pricing differences between the RTOs and favors the direction of PJM into MISO.

As shown in Figure 7, under either trade-ready option (rate- or mass-based) changes to the level of interchange were modest. In contrast, when PJM resources are subject to a different emission standard than MISO resources ("PJM Mass MISO Rate" or "PJM Rate MISO Mass"), the locational marginal price (LMP) differentials (See Figure 9) can expand significantly which is indicative of very different utilization of the transmission system. In both of the patchwork scenarios, the ERC price is much higher than the allowance price (See Figure 4). As the policy gap widens, energy is more likely to flow from the system with the lowest CO_2 price to the system with higher CO_2 prices. To preserve generation and load balance, a significant shift in economic interchange means that resources in one system are utilized less, whereas resources in the other system benefit from higher operation to serve a fixed amount of load.

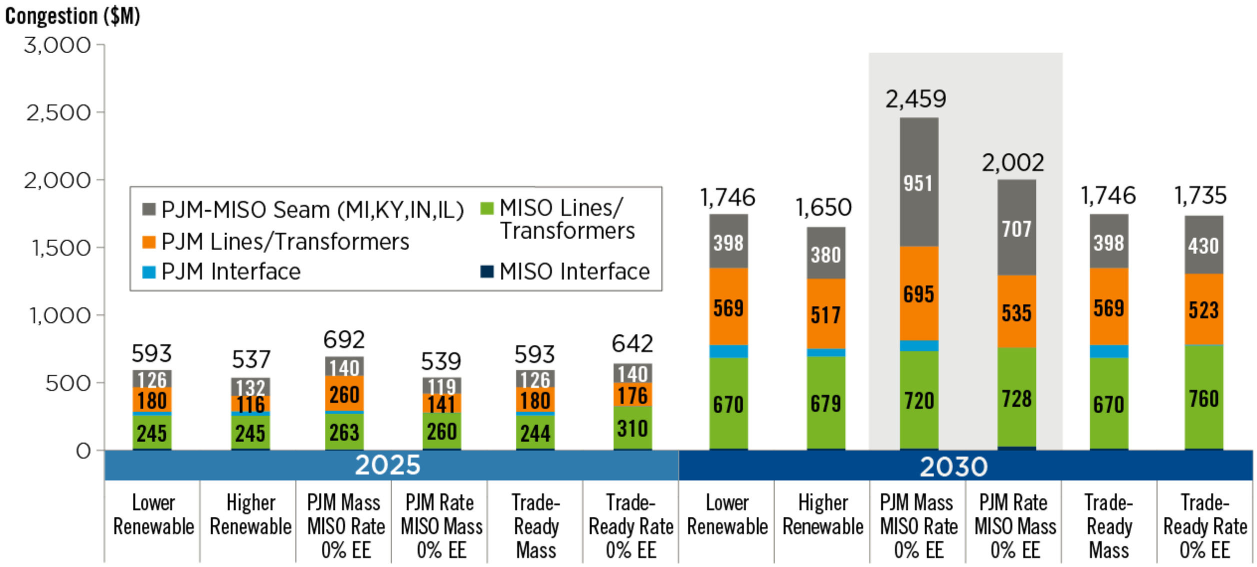
[14] MISO and PJM modeled firm purchases and sales to external regions. Future bilateral agreements or economic sale/purchase opportunities with non-PJM or non-MISO entities are not modeled and could influence how much PJM and MISO transact with each other.

Transmission Congestion

The incremental cost to operate generation on a transmission constrained system is called transmission congestion and is shown in Figure 8 for each scenario studied in 2025 and 2030.

The categories are used to illustrate how both the physical location of congestion and the types of devices with the heaviest loading change by scenario. Therefore, it is a useful metric to understand where new infrastructure is needed to support the most efficient delivery of generation to load.

Figure 8. Transmission Congestion by Physical Location and Equipment Type



Transmission congestion costs can increase as a function of various drivers, including

- higher fuel prices;
- higher load levels or shifts in where load is concentrated;
- new economic generation constructed without associated transmission reinforcements,
- transmission and generation outages; and also
- policy/regulatory decisions that shift where the most economic generation is located.

The first three were the primary drivers for the increase in congestion observed between 2025 and 2030. The transmission model used in the analysis contained sufficient upgrades that by 2025 congestion remains low relative to the historical levels. By 2030, however, system operation has changed significantly enough to drive much higher levels of transmission congestion. CO_2 policy implementation clearly had an impact on 2025 as illustrated by the "PJM Mass MISO Rate", (29 percent transmission congestion increase), and "Trade-Ready Rate" scenarios, (20 percent transmission congestion increase), but its impact was much more pronounced by 2030 when the CO_2 emission reduction targets reach their highest levels.

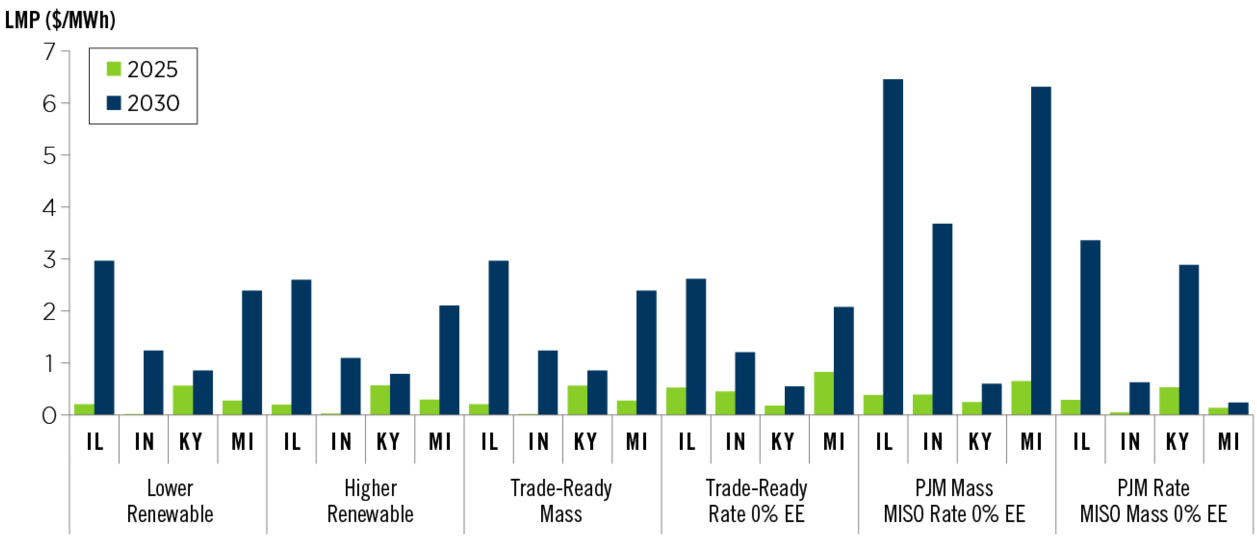
One way to interpret transmission congestion is that it measures the level of deviation in system operation from the operation originally intended for the existing physical infrastructure (i.e. transmission lines, transformers, control devices). The results illustrate that consistent policy implementation across states represented by the trade-ready scenarios results in less congestion costs on the MISO and PJM systems as both the MISO and PJM generators receive the same economic signal in the form of a common CO_2 price. Adoption of a common policy leads to transmission congestion increasing by no more than 5 percent in 2030, whereas patchwork approaches led to a 21 percent and 41 percent increase in congestion respectively.

The transmission congestion results can be directly tied to the physical flows observed in Figure 7 in which patchwork approaches doubled the average interchange on the MISO/PJM interface or completely reversed flows depending on which system was subjected to the more stringent CO_2 policy. The results highlight the importance of interregional coordination in implementing new policies/regulations to mitigate unintended consequences on the transmission system.

Locational Marginal Prices

Figure 9 shows the absolute differences in LMPs at the MISO and PJM hubs in the seams states. Each state's LMP represents a weighted average of the individual station (node) LMPs within the state.

Figure 9. Absolute value of PJM and MISO LMP differential for each seam state

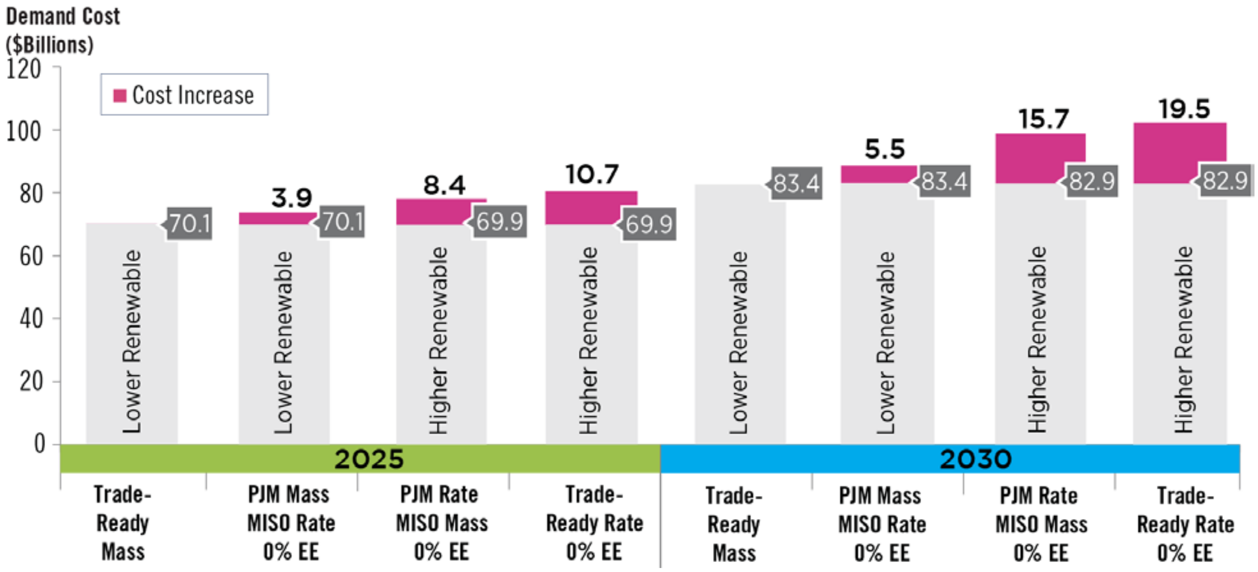


The effects of state policy choices on congestion costs and economic interchange are also evident in the LMPs observed within the seam states. Enforcement of different CO_2 policy for resources participating in either RTO can cause significant distortion in pricing observed across any individual state. In contrast, under either full trading (rate-based or mass-based) scenario, the LMP differential remained relatively consistent with the base cases in which no CO_2 policy was enforced. Coordinated policy implementation across states is therefore important for assurance of efficient pricing for customers in the seam states.

Energy Demand Costs

Figure 10 illustrates the demand cost associated with the base case(s) and the incremental cost increase as a result of state policy choices in response to the CO_2 regulation. The demand cost represents an aggregation of the cost paid at each station (node) for each unit of energy (MWh) consumed at the LMP.

Figure 10. Demand Cost for base cases and increase in demand cost due to CO_2 limitations



Transmission congestion generally represents a fraction of the total LMP. In many hours of the year, the system is either unconstrained or the cost for mitigating congestion is not significant when compared to the energy cost. The CO_2 prices shown in Figure 4 can be significant and are a part of each affected resources' energy offer into the market in every hour.

Consistent with observations on production cost, trade-ready mass compliance did not lead to incremental demand cost. Trade-ready rate resulted in the most significant increase to demand cost because both MISO and PJM resources must purchase ERCs, above $35/ERC, in both 2025 and 2030. Under the patchwork scenarios, resources in one system are required to comply with allowances, which remain below $1/ton in both years. Compared to trade-ready rate-based, under the patchwork approaches the system that faces the lowest cost to comply with the regulation will sell more energy into the higher priced system, which helps offset increases in demand cost for both systems.

Energy Efficiency Credit Sensitivity

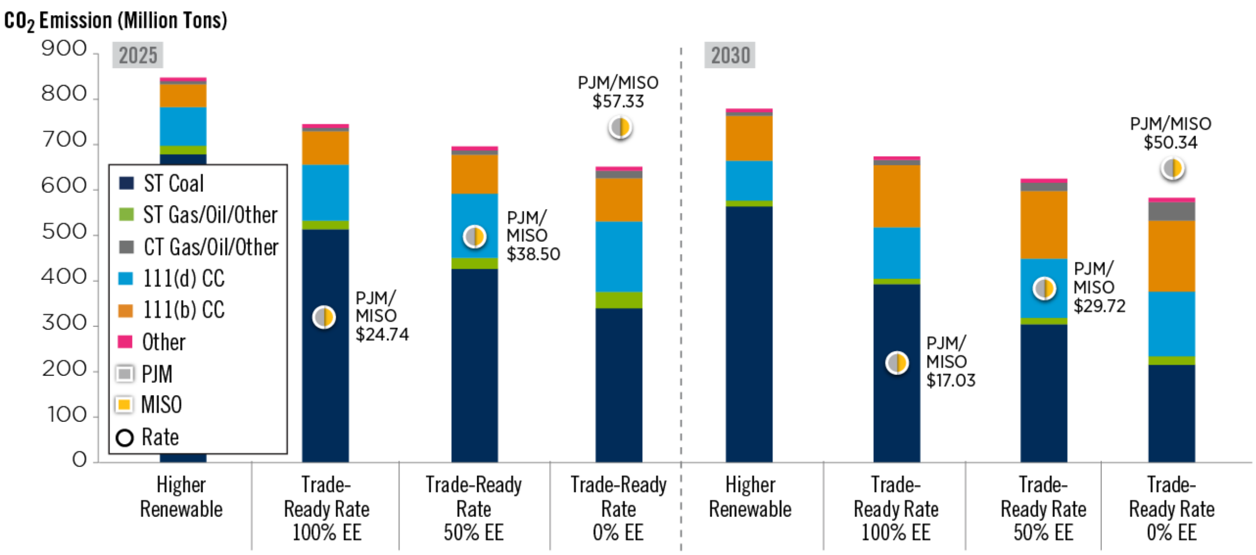
The EPA identified energy efficiency (EE) as one of the qualifying technologies that could generate ERCs that are useable by affected thermal resources to demonstrate compliance with their rate targets. States complying on their own would need to demonstrate a plan that meets the EPA's standards for measurement and verification before awarding ERC credit for new EE projects. Energy efficiency applies to a wide range of devices and classes of load (e.g. residential, commercial and industrial). Developing a common measurement and verification system for EE across a broader trading region (involving parts of multiple or even entire states) could present an even greater challenge. Recognizing the difficulty in accounting for every MWh saved by energy efficiency investments, the coordinated analysis examined the economic and compliance benefits of accounting for different levels of energy efficiency.

Assuming states adopt a trade-ready rate compliance strategy, MISO and PJM chose three levels of EE eligible to earn ERCs: 100 percent, 50 percent and 0 percent. These scenarios utilized the same set of resources as the "higher renewable" base case, but instead of the blended Henry Hub gas forecast, the sensitivity simulations used a "2016 EIA Annual Energy Outlook" reference gas price. The results of these scenarios are discussed below.

CO_2 Price and Market Price Impacts

Figure 11 illustrates the total CO_2 emissions and the associated price for each scenario as the level of energy efficiency eligible to generate ERCs is changed.

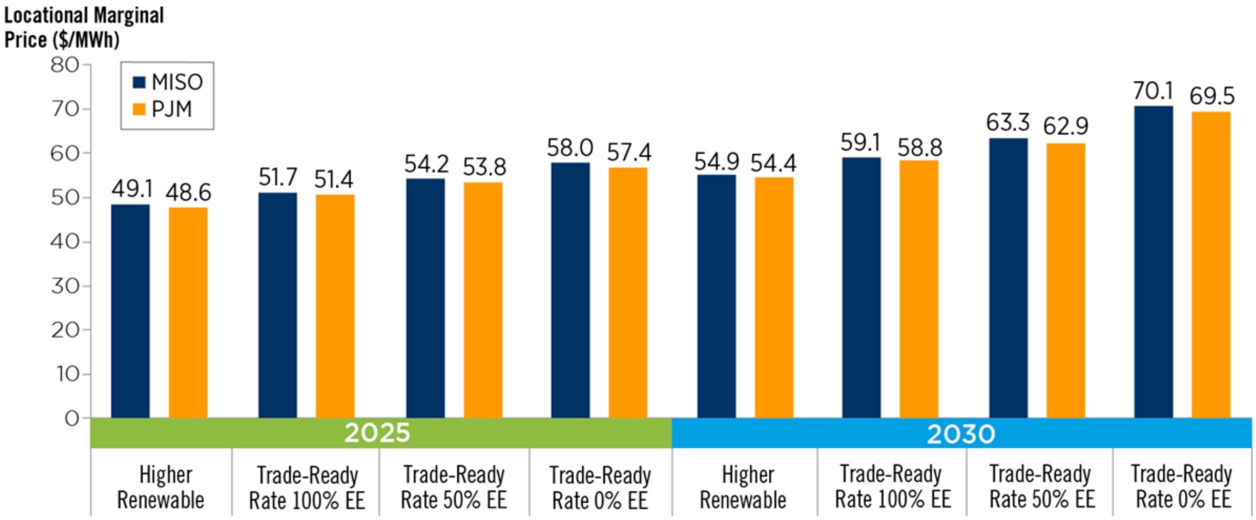
Figure 11. Total CO_2 emissions and emissions prices



Each scenario has the same amount of net load that has to be served by PJM and MISO generation. The only change by scenario is the level of participation of energy efficiency in ERC trading markets. Figure 11 shows that wider availability of ERCs generated by energy efficiency not only decreased CO_2 prices, but also significantly reduced the amount of CO_2 reductions that needed to be made by resources for compliance with the rate-target. On average ST Coal emits 1 ton of CO_2 for every MWh produced. Although significant reductions still had to be made in the "100 percent EE" scenario, this scenario preserved the energy (MWh) output from these units much more effectively compared to the other compliance scenarios.

As shown in Figure 12, the ability to convert investments in energy efficiency into ERCs directly affects consumer energy cost at the wholesale level. While the CO_2 emission constraints generally increased energy prices, wider availability of EE credits resulted in increased prices in the range of 5-to-8 percent as opposed to the 18-to-28 percent observed in the "0 percent EE" scenarios.

Figure 12. Locational Marginal Prices for the PJM and MISO region

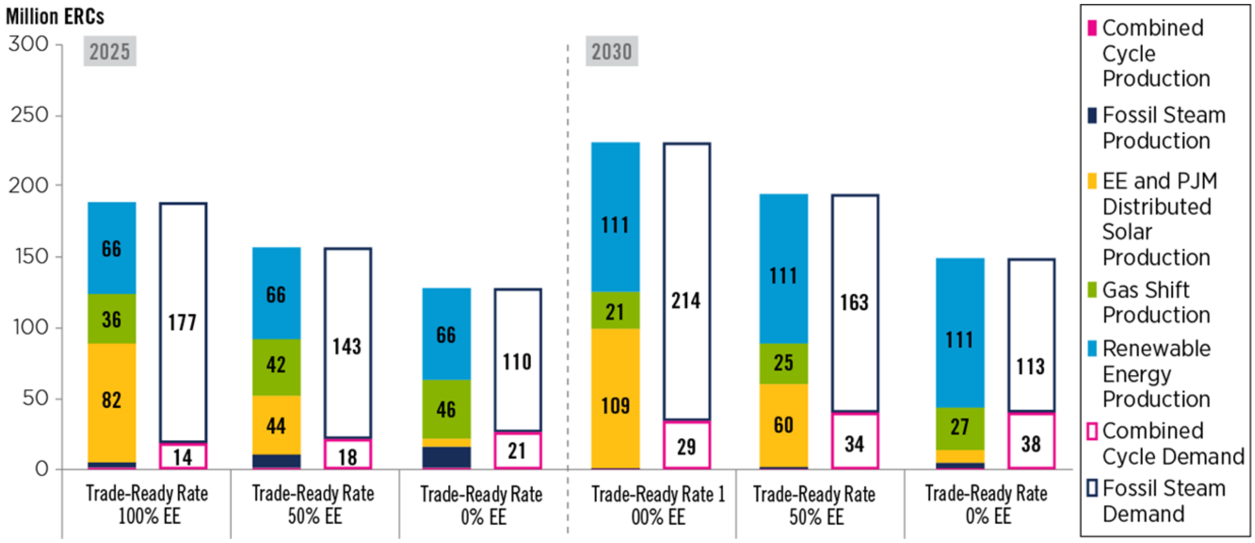


Rate-Base Supply and Demand Balance

Per the EPA's guidance, some resources are producers of ERCs, whereas others are consumers of ERCs. The rate of production or consumption is based on performance relative to the trade-ready rate-based targets for fossil resources. The model solves for an ERC price that enables the market to balance supply and demand for ERCs. As shown in Figure 11, decreasing the ability of energy efficiency to generate ERCs resulted in much higher CO_2 prices in both 2025 and 2030. As the CO_2 price increases, more coal units reduce their output; as a result, overall demand for ERCs goes down.

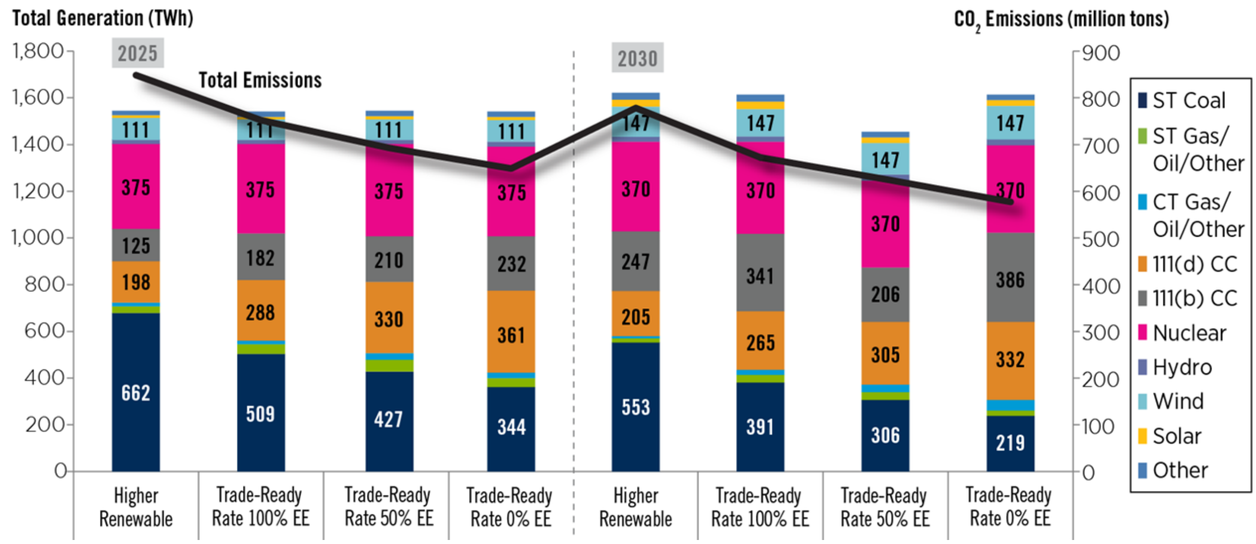
The resource mix during a given year is fixed; the output of existing renewable resources is also fixed. Consequently, as coal reduces its output, lower-emitting resources must increase their output to ensure load continues to be served in the energy market. This is the driver for the increase in ERC demand observed for combined cycle generation in both 2025 and 2030 as shown in Figure 13. In 2025, the emissions rate targets are high enough such that some fossil steam resources are also incentivized to increase their output for the production of ERCs.

Figure 13. ERC supply and demand by technology type



By 2030, the emissions rate targets achieve their final levels. However, the CO_2 prices go down (See Figure 11) and the demand for ERCs increases significantly relative to 2025. Counter to the latter observations, total emissions go down in 2030 for each scenario, relative to 2025 levels. The additional supply of ERCs created by higher penetration of renewable resources and new energy efficiency deployment explains the declining CO_2 price and even lower fossil unit generation as shown in Figure 14. Lower CO_2 prices are only partially responsible for the rise in ERC demand observed in 2030, relative to 2025 levels. By 2030, the CO_2 targets are lower, which means each generator has to purchase more ERCs for every unit of energy production. This is the primary driver for higher ERC demand by 2030.

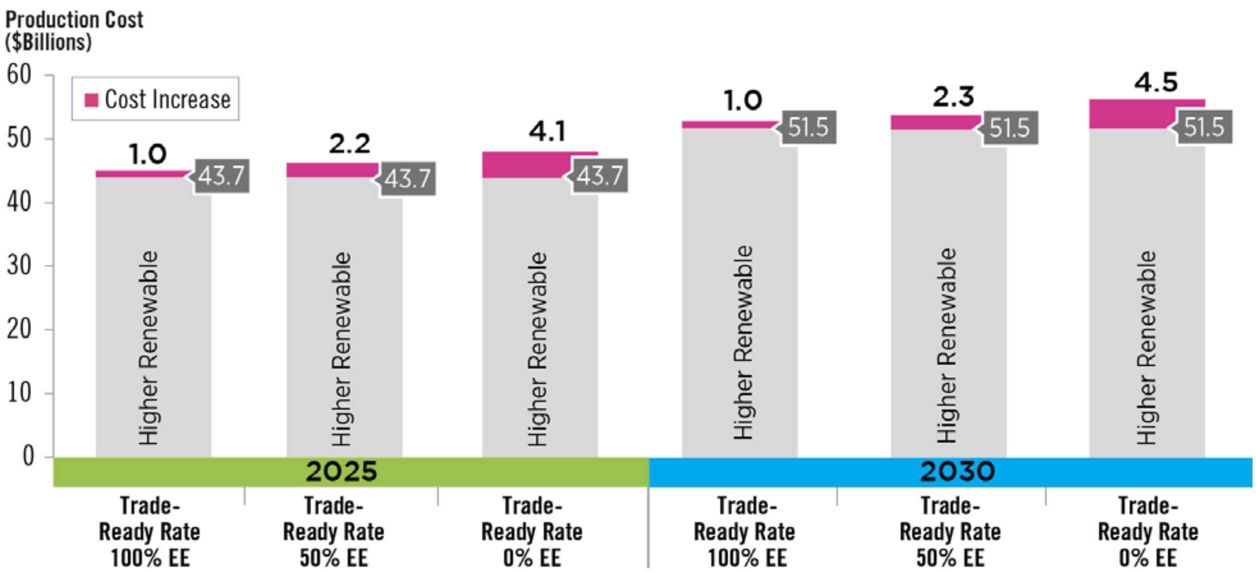
Figure 14. PJM and MISO total generation and total CO_2 emissions



Generator Production Cost

As shown in Figure 15, MISO and PJM states can avoid the most significant increases in production cost by standardizing energy efficiency measurement and verification for generating ERCs.

Figure 15. Increase in MISO and PJM's generator production costs under energy efficiency sensitivity



Each of the scenarios has the same level of investment and deployment in new energy efficiency, however in the scenarios labeled “50 percent EE” and “0 percent EE” there are lost compliance savings as only 50 percent or 0 percent of the embedded energy efficiency is used for compliance.

Broader Trading Regions Sensitivity

Today there are two major greenhouse gas trading programs in the United States – the Regional Greenhouse Gas Initiative (RGGI) comprised of nine northeastern states and AB32, an economy-wide CO_2 trading program in California. Under this case study, PJM and MISO sought to understand the economic benefits of broader trading assuming that a national CO_2 regulation were implemented. This fundamental economic analysis can be applied to any regulation under which states use the same compliance instrument (e.g. allowances or ERCs) but also for which states can make policy choices that affect the instrument’s fungibility across state lines or regions.

Specifically, this study examined resource performance and economic differences that arise should emissions trading be limited to occur between resources participating in a single regional market (such as PJM or MISO) versus interregional trading.

The scenarios in this section are described in Table 3 below.

Table 3. Broader trading region sensitivity description

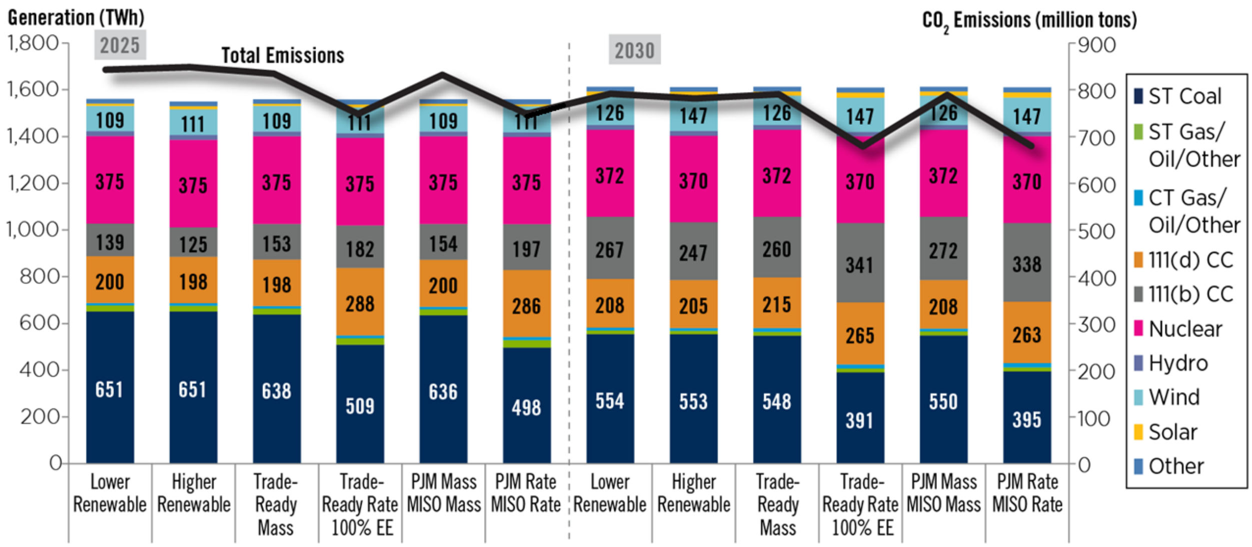
Scenario	Base Case	MISO PJM Trading	MISO Trading Instrument	PJM Trading Instrument
Trade-Ready Mass	Lower Renewable	Yes	Allowance	Allowance
Trade-Ready Rate	Higher Renewable	Yes	Emission Rate Credit	Emission Rate Credit
MISO Mass, PJM Mass	Lower Renewable	No	Allowance	Allowance
MISO Rate, PJM Rate	Higher Renewable	No	Emission Rate Credit	Emission Rate Credit

The scenarios evaluated in this section each use the “2016 EIA Annual Energy Outlook” Henry Hub reference gas price forecast. The following sections discuss the results.

Generator Fuel Mix and Production Cost

Figure 16 illustrates both the resulting fuel mix and total emissions observed for both base case models and the compliance scenarios.

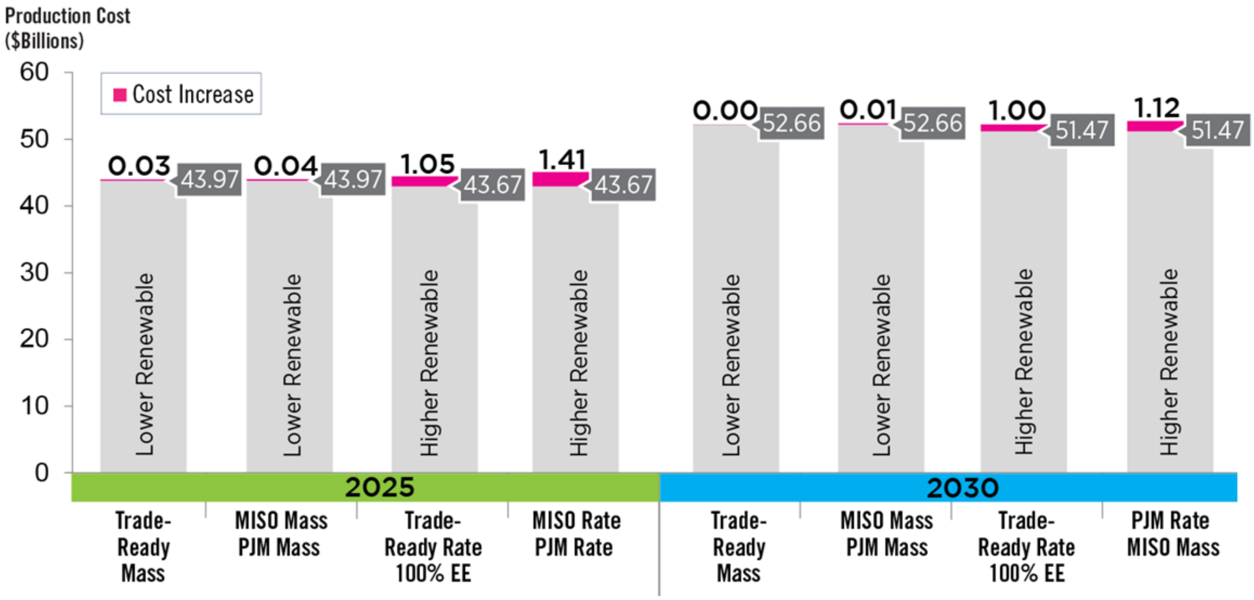
Figure 16. Fuel mix and CO_2 emissions under trading region sensitivity



As shown in Figure 16, the trade-ready mass-based and trade-ready rate-based scenarios resulted in less of a reduction to coal unit output, relative to the base cases, than would occur in the scenarios that restrict interregional trading. Trade-ready mass-based again produced the smallest shift in production from the base case without CO_2 reduction targets in both 2025 and 2030. This observation is consistent with those found in scenarios using the blended gas price discussed in previous sections.

Scenarios with the least amount of change in generation dispatch relative to the base case should also be expected to result in the lowest changes in generator production cost. As shown in Figure 17, scenarios with interregional trading (i.e. trade-ready mass-based and trade-ready rate-based) resulted in lower increases in production cost relative to the limited trading scenarios using the same commodity (i.e. ERCs or allowances). The results demonstrate the value of coordination between RTOs in weathering potential disturbances to the most efficient generator operation as new regulatory requirements are established.

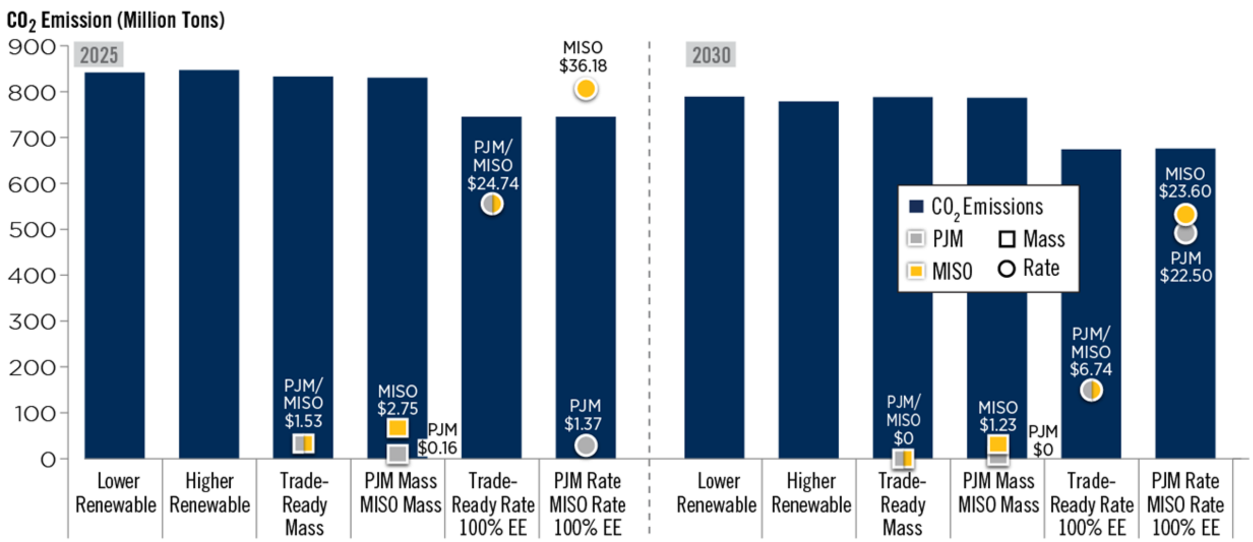
Figure 17. Aggregate production cost increases in MISO and PJM under trading region sensitivity



CO_2 Emissions, Emissions Prices and Demand Cost Impacts

As with the EE sensitivity, this study examined the CO_2 emissions and prices that resulted from variations on the size of the emissions trading market. The results are illustrated in Figure 18.

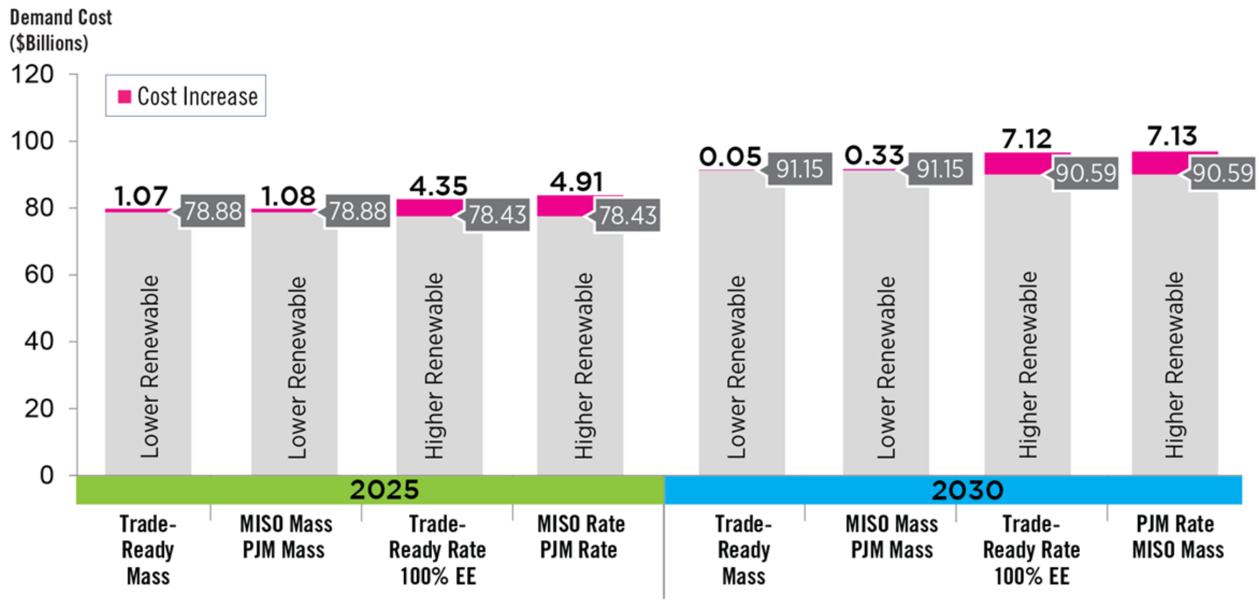
Figure 18. MISO and PJM CO_2 emissions and prices under trading region sensitivity



The CO_2 price that forms as a result of trading (i.e. trade-ready) is expected to either be lower than both independent trading region CO_2 prices or be in between the two independent trading regions' CO_2 prices. Whether, the former or latter occurs is a function of the stringency of the regulation by independent region.[15] When one region has a lower CO_2 price than the interregional CO_2 price, this result should not be misinterpreted as enhanced economic efficiency. In organized markets, energy should flow from the lowest-priced system to the higher-priced system. Higher compliance cost experienced in one region is therefore transmitted to both regions through higher resource energy offers and market prices (i.e. locational marginal prices).

As mentioned previously demand cost represents an aggregation of revenues collected from loads paying market prices for energy withdrawn at individual stations (i.e. nodes) throughout the PJM and MISO system. The increase in demand cost arising from complying with the CO_2 regulation is shown in Figure 19 below.

Figure 19. Aggregate demand cost increases in MISO and PJM under trading region sensitivity



Full trading across the MISO and PJM regions resulted in lower increases to demand cost compared to the increases observed under restricted trading. Again, rate-based compliance led to higher demand charges than mass-based compliance. Both the level of energy efficiency deployed and renewable resource output is fixed within the model, which means that these technologies' ability to produce ERCs is also fixed. The increase in demand cost under rate-based compliance is indicative of higher ERC prices that reduce demand for ERCs from coal plants and higher substitution from coal to natural gas-fired technologies in the fuel mix.

[15] This observation was also found for state versus regional compliance CO_2 prices in PJM's CPP Compliance Assessment. Some states were observed to have a 0 CO_2 price, which is indicative of the state having excess allowances or ERCs. Without accounting for the benefits of selling the excess allowances or ERCs, the benefits of trading were still illustrated by lower regional production cost.

Conclusion

Observations from the analysis are intended to help states in the MISO and PJM regions better understand how inter-regional coordination can help states achieve policy objectives with the least-adverse impacts to power system operation and at the lowest cost. The economic fundamentals rooted in the operation of organized wholesale electric markets can easily be extended to evaluation of emissions policy. States, utilities and other entities can consider the observations made from this analysis within the specific context of the Clean Power Plan or in a broader context as they consider other policy goals that can influence already dynamic economic interactions in modern wholesale electric markets.

From this analysis, the following key observations were observed:

- External economic drivers may overshadow state policy choices. Natural gas prices heavily influence the cost and impact of state policy objectives by influencing resource economics (zero-emitting project viability).
- Standardization of state policy decisions may reduce associated program costs. Standardization of energy efficiency measurement and verification facilitates commoditization of credits across broader markets; and would enhance energy efficiency's value to consumers by offsetting deployment costs.
- Non-similar state policies can drive significant economic distortions along the MISO-PJM seam and exacerbate transmission cost impacts. Conversely, the ability to transact fungible products amongst states results in greater market efficiency.

Appendix

Additional Key Modeling Inputs

PJM and MISO used Energy Exemplar's PLEXOS ® Integrated Energy Model (PLEXOS) to perform the joint coordinated analysis of CPP compliance scenarios. PLEXOS enables an exact representation of EPA's rate-based and mass-based constraints within the unit commitment and dispatch optimization.

PLEXOS was used to perform the following as part of the MISO/PJM Coordinated CPP Analysis:

- Chronological dispatch of generating resources subject to transmission constraints (SCED)
- Environmental limits analysis short-time horizons for simultaneous evaluation of rate (lb/MWh) and mass-based (tons) emissions limits

Key inputs to the PLEXOS model are detailed in Table 4

Table 4. Model Inputs and Assumptions

Input	Primary Source for Data
Load Forecast	• 2016 PJM Load Forecast (0.7% Peak and 0.8% Energy Growth) • 2017 MTEP Load Forecast (0.7% Peak and Energy Growth)
DG/DR/EE (2030)	• PJM: DG - 2.2 GW, DR – 3.6 GW, EE- 15.7 GW • MISO: DG - 0 GW*, DR – 4 GW, EE- 2.8 GW *Included in solar PV economic additions in Slide 9
Transmission Model	Jointly developed power flow case

Forecast Fuel Prices	• Gas – Blend of the following:
	  • EIA 2016 Annual Energy Outlook
	  • IHS CERA September 2016 Natural Gas Briefing
	• Other - ABB NERC Spring 2016 database

Unit-Level Operating Characteristics	• ABB Simulation Ready database
Generation Model	• MISO MTEP17 Policy Regulations Model • PJM Trade-Ready Rate and Trade-Ready Mass Scenarios
Solar and Wind 8760 Shapes	• National Renewable Energy Laboratory
Transmission Constraints	• 2016 PJM Market Efficiency Basecase • MISO MTEP17 Policy Regulations Model • Additional flow-gates Identified during model development
PJM Reactive Interface Constraints	PJM Market Efficiency Assumptions
Economic Hurdle Rates	• MISO-PJM: $8/MWh • PJM-MISO: $1/MWh