October 8, 2014

PJM 111(D) Modeling

I.   Overview

The Organization of PJM States, Inc. (OPSI) requested PJM Interconnection staff to perform analyses of the potential impacts of U.S. EPA's proposed 111(d) Carbon rule.[1] OPSI's request outlined base case, regional compliance case, regional compliance case scenarios and state-by-state compliance case modeling assumptions.

PJM has committed to performing the requested analyses of years 2020, 2025, and 2029 and will augment them with additional sensitivity scenarios focused on generation availability and energy efficiency assumptions. The analyses results will include (by transmission owner zone, state and RTO region): carbon price, carbon emissions rate, Locational Marginal Prices, energy market load payments, percentage of generation by fuel type, and generator net energy market revenue (net of going forward fixed avoidable capital costs).

The scope of the initial analyses does not include a transmission planning reliability analysis. PJM will not be identifying NERC transmission planning criteria violations or determining the transmission solutions to address any criteria violations. PJM's modeling will be an energy market analysis. However, PJM intends to use the results of this initial energy market analysis to inform future "at-risk" scenario studies to be performed as part of the PJM Regional Transmission Expansion Planning process.

PJM is targeting late October to complete and publish initial results from this analysis and will offer sessions with the states and with stakeholders to review the initial results. PJM will comply with its Operating Agreement provisions pertaining to confidential data.

PJM's analyses will differ from the EPA's analysis of its proposed carbon rule. PJM will use assumptions consistent with the assumptions used in its Regional Transmission Expansion Plan Market Efficiency Analysis, and PJM will run sensitivity analysis of generation availability and energy efficiency. Additionally, PJM will not model the impacts of each of the EPA's proposed building blocks; potential coal unit efficiency improvements will not be modeled. Also, PJM will assume that emissions from new generation will not be included in the assessment of 111(d) compliance for the purpose of this model but rather that such units will need to comply with 111(b) instead.

II.   Modeling Approach

PJM will perform the analyses using PROMOD IV, which is a market simulation tool that models an hourly security constrained economic generation commitment and dispatch. The modeling requires various input assumptions, described in more detail below.

PJM will use PROMOD to complete the regional compliance and state–by-state compliance cases and sensitivity scenarios. PJM will use a separate dispatch program to determine the

---

[1] See OPSI's request posted on PJM.com at http://www.pjm.com/~/media/documents/reports/20140905-opsi-data-request-for-section-111d-modeling.ashx

initial carbon emission prices to input into PROMOD to perform the state–by-state compliance case (for the 12 states with a compliance obligation under the EPA proposed carbon rule) for year 2020. For both the regional and state-by-state compliance cases PJM will iterate on a solution until the total annual emissions are within a reasonable tolerance (+/- 2.5 percent) of the limit.

III.   Calculating Mass limits

PJM's modeling effort requires the determination of the emission target that must be satisfied on a regional basis and state-by-state basis. For ease of modeling within PROMOD, PJM will use a mass-based emissions target. Below is a description of how PJM calculated the mass-based target for each state based on data provided by EPA in the technical support documents accompanying the proposed carbon rule. PJM relied on this EPA data to calculate the mass-based emissions limit. With the exception of one regional compliance case scenario, PJM will not use the EPA data as the source for resource assumptions in the modeled compliance case scenarios.

State Mass Limit Calculations

The EPA provided the "Goal Computation Technical Support Document"[2] for calculating the CO_2 rates by state. The document provides guidelines for how each building block contributes to the rate calculation. It also describes the criteria for resource inclusions and exclusions. In addition to the written description of the policy calculations, the EPA provided an Excel file, Data File: Goal Computation - Appendix 1 and 2 (XLS) [3] containing the 2012 generation, emissions and retail sales by state. Within this data file, the EPA provided expected renewables and energy efficiency under both the proposed goals as well as alternative goal calculation. To support users in identifying the resources included and excluded from the policy the EPA also provided an appendix containing the specific resources included in the goal computation. The EPA identified the units within each state by prime mover and fuel. The following classifications were used by the EPA: Steam Turbine Coal ("Coal Steam"), Natural Gas Combine Cycle ("NGCC"), Steam Turbine Oil/Gas ("OG Steam"), and a final category, "Other," that includes high utilization simple-cycle gas/oil turbine ("SCT"), integrated gasification combined-cycle ("IGCC") and other units meeting the EPA's emissions monitoring criteria. Emissions from those categories of resources were included in the goal computation based on 2012 thermal output.

A. Treatment of Thermal Resources (ST Coal, NGCC, OG Steam, Other)

For states wholly within the PJM footprint, PJM staff utilized the EPA's assumption of resource thermal output and emissions. For states containing resources belonging to both PJM and a neighboring balancing area, PJM staff included only the megawatt-hour output from resources operated within the PJM balancing area.

B. Treatment of Energy Efficiency

PJM staff used the EPA's projection of avoided generation sales due to energy efficiency (EE) in the computation of mass limits. For states whose loads are wholly served by the PJM grid, PJM staff utilized the EPA's projected EE value as provided in the goal computation data file. In

---

[2] http://www2.epa.gov/sites/production/files/2014-06/documents/20140602tsd-goal-computation.pdf
[3] http://www2.epa.gov/carbon-pollution-standards/clean-power-plan-proposed-rule-technical-documents

that data file, EE is calculated as a percentage of 2012 electric sales adjusted for the level of in-state generation serving load within the state. To calculate the PJM component of EE, The EPA's projected EE value (megawatt-hours) by state was adjusted based upon the percentage of sales (megawatt-hours) within the PJM region relative to state-wide sales. The resulting value was used in the mass-limit calculation.

C. Treatment of Renewable Generation

PJM staff utilized the EPA's projection of renewables (excluding existing hydroelectric power) in the mass-limit calculation. For states whose load is wholly served by the PJM grid, the EPA's projected renewable megawatt-hours were taken as is. However, for states with multiple balancing authorities, including PJM, the amount of renewables was reduced based upon the percentage of PJM sales relative to state-wide sales. The resulting value was used in the mass-limit calculation.

D. Treatment of Nuclear Generation

The EPA provided "at-risk" megawatt-hours in the data file by state. For states whose generation is wholly within the PJM balancing authority, the "at-risk" megawatt-hours were taken at 100 percent of the EPA's value. However, for states with multiple balancing authorities, PJM staff determined the percent of 2012 nuclear output produced by nuclear units classified as PJM resources within the state. The resulting percentage was applied to the EPA's megawatt-hour value, which was then included in the mass-limit calculation.

E. Calculating the Mass Limit

PJM staff converted the state CO_2 rates outlined in the EPA's proposal to mass-based limits to use in the PROMOD IV production cost tool. The sum of megawatt-hours produced by thermal generation resources in PJM, the megawatt-hours the EPA projected for renewables/energy efficiency in PJM, and the megawatt-hours for at-risk nuclear was multiplied by the state-rate goal to derive the mass-limit (CO_2 tons) for each state in the PJM footprint. The individual state mass-limits were summed to calculate the PJM regional mass limit.

IV. Simulation Approach

Using the EPA's 111D applicability criteria, PJM will run production costing simulations where the emissions of applicable units are monitored for a year for each of the requested years (2020, 2025 and 2029). A CO_2 compliance price ($/ton) will be calculated for any scenario that binds on the regional mass-based emissions limit or state mass-based emissions limit.[4] In the

---

[4] Similar to a transmission constraint that causes generation resources to be re-dispatched to remove the potential flow violation, the mass-based limit is a constraint on unit operation that forces a re-dispatch of PJM resources until the emissions violation is no longer present. The increase in cost represented by the additional constraint on unit operation, is represented by the CO_2 price ($/ton). For any scenario where the aggregate emissions in the region (or state if it is the state-by-state scenario) exceeds the emissions limit, PJM will iteratively determine a CO_2 price that allows a combination of economically dispatched units to meet PJM's load requirements with an aggregate emissions level that is within a tolerance band (+/- 2.5%) of the mass based limit.

regional simulation, the same CO_2 price will then be applied to all qualifying units[5] within the PJM footprint. For the state simulation, a different CO_2 price will be applied in each state.

If any scenario does not bind on the mass-based emissions limit, then there are no additional compliance costs beyond the level of incremental investment in energy efficiency and renewable generation. Although there are other behavioral, economic and/or policy factors driving investment in energy efficiency and renewable generation, PJM is not attempting to identify those costs through this production cost modeling analysis. The analysis will show only – based upon various assumptions on the level of the building blocks – whether the PJM footprint or an individual state is under or over the mass-based emissions limit.

In addition, PJM staff will assess unit revenues from qualifying units for selected scenarios that bind on the limit to determine whether their simulated energy market revenues are sufficient to cover their going forward fixed avoidable costs.

Given the limited time to complete the analyses, analysis of potential retirement of uneconomic units will be performed for only one scenario – the "Economic Case" described below. (PJM is using PROMOD to do the simulation, not an integrated planning and market optimization tool which determines retirements and new entrants.) In that scenario, PJM will replace identified at-risk generators with existing NGCC queue capacity if the generation capacity in the model falls under the expected Installed Reserve Margin target in any of the simulation years. The uneconomic units will be assumed to be retired based purely on economics. The purpose of retiring the units in the model is to identify the energy market impacts of the retirements relative to the reduction in CO_2 price.

V. Base Case

The base case, or what the EPA refers to as Business as Usual Case, will assume no EPA carbon rule is in effect. The base case will be consistent with the PJM 2014 RTEP Market Efficiency Base Case and results for years 2020, 2025, and 2029.

VI. Compliance Cases

PJM will compare the regional and state-by-state compliance case results to the base case results to show carbon price, emission rate, LMP, load payment, generation fuel mix, and generation net revenue impacts.

To establish the carbon emission targets to use in the compliance case modeling, PJM will roll up the emission targets as proposed by the EPA for each generator within the PJM footprint of the state for the years 2020, 2025, and 2029, as described above in Section III, "Calculating Mass Limits."

---

[5] Units meeting the 111D inclusion criteria – see http://www2.epa.gov/sites/production/files/2014-06/20140602tsd-plant-level-data-unit-level-inventory_0.xlsx

A. Compliance Case Assumptions

PJM will use input assumptions consistent with the 2014 RTEP Market Efficiency Analysis, including fuel costs, emissions costs, load forecasts, demand resource projections, and expected future transmission topology.[6] PJM uses a commercially available database to obtain the fuel price forecast for each fuel type used in the PROMOD model. Forecasts for short-term gas and oil prices are derived from New York Mercantile Exchange future prices. Long-term gas, oil, and coal forecast prices are based on vendor provided economic forecast. In addition, vendor provided natural gas basis adders are applied to account for commodity transportation costs to each PJM transmission zone.

PJM will include all future generation in the PJM queues that executed a Facilities Study Agreement or Interconnection Service Agreement and associated network upgrades. Existing generation which the owner has notified PJM that it plans to deactivate will be modeled as being off-line in the studies.

The PROMOD database and Market Efficiency Base Case contains emissions rates (lb/mmbtu) for each thermal resource modeled within PJM. For this analysis the CO_2 rate was checked against historical data publicly available in the EPA Continuous Emissions Monitoring System "CEMS" database. New unit prototypes are defined for the PJM region and are provided within the commercially available database accompanying the PROMOD data release. When adding a new unit from the queue, PJM used the unit's prime mover and fuel provided in the PJM interconnection studies to identify the appropriate unit prototype to model. The emissions rate and other operating characteristics for new units are based on the default unit prototypes.

Additionally, for the energy efficiency assumption in the compliance case analysis, PJM will assume the state targets for energy efficiency identified in the EPA proposed carbon rule are met. PJM will run additional sensitivity analysis assuming lower energy efficiency accomplishments. To model the impact of energy efficiency, PJM will reduce the projected load forecast. PJM's January 2014 Load Forecast Report[7] provides the transmission zone load and energy data that will be included in the base case model. PJM will then use the load forecast projection, adjusted as necessary for the energy efficiency assumption, to calculate the Renewable Portfolio Standard target to model for each state. For scenario simulation, PJM will use the RPS goals for each state as set forth in the PJM Regional Transmission Expansion Planning RPS Scenario analysis and not the RPS targets that EPA used to set its proposed emissions limit for each state.[8] As part of the final technical report, the renewable energy assumption modeled by scenario will be included in an appendix.

---

[6] See Transmission Expansion Advisory Committee presentation reviewing market efficiency analysis assumptions: http://pjm.com/~/media/planning/rtep-dev/market-efficiency/market-efficiency-input-assumptions.ashx

[7] http://www.pjm.com/~/media/documents/reports/2014-load-forecast-report.ashx

[8] For additional information on the state renewable portfolio requirements used in PJM planning studies and this 111(d) Carbon Rule analysis, – See Table 6.1 State RPS Initiatives in PJM (pp. 84-85), and Map 6.1 -State Renewable Portfolio Requirements (page 86) in the 2013 PJM RTEP – REGIONAL TRANSMISSION EXPANSION PLAN, http://www.pjm.com/~/media/documents/reports/2013-rtep/2013-rtep-book-2.ashx

The model used in the PROMOD IV analysis will include specific transmission constraints: thermal constraints and reactive interface constraints consistent with the model used in the 2014 RTEP Market Efficiency Analysis. The model includes effects of future transmission expansion projects included in the Regional Transmission Expansion Plan.

B. OPSI Requested Regional Compliance Cases for years 2020, 2025, and 2029

PJM will model the energy efficiency targets identified in the EPA's proposed carbon rule along with the necessary generation to satisfy all PJM states' RPS requirements based on the 2014 January PJM load forecast adjusted by the energy efficiency assumption. The level of renewables modeled will be based on the RPS requirements of the PJM states for each of the study years. PJM will not include any assumptions to change the dispatch order of generation, to increase the efficiency of generation resources or to reduce the level of nuclear unit availability. Those assumptions will remain consistent with the base case.

- Case i: only include renewables currently in the PJM interconnection queues
- Case ii: only model 50 percent of the EPA assumed energy efficiency
- Case iii: assume natural gas prices 50 percent higher
- Case iv: assume a 50 percent reduction in nuclear

C. OPSI Requested State-by-State Compliance Case For Year 2020:

PJM will utilize the regional generation commitment and dispatch model in PROMOD IV but include the state-specific carbon prices established by a separate modeling analysis for the 12 states that have compliance obligations. PJM will model the energy efficiency targets as identified by the EPA and will adjust the RPS target based on the lower load forecast that results from the energy efficiency assumption.

D. Additional Regional Compliance Case Scenarios For Years 2020, 2025, and 2029

PJM will run additional scenarios to further stress the PJM region's ability to meet the 111(d) emissions criteria.

1) **PJM (1) EPA Renewables + 50% Energy Efficiency:** The EPA projected fewer renewables than PJM has projected in the OPSI requested scenario described above. In addition, the level of energy efficiency assumed by the EPA is much higher than the observed energy efficiency commitments in PJM Reliability Pricing Model Base Residual Auctions. (RPM is PJM's capacity market.) Therefore, PJM will run an additional analysis using the EPA's projection of renewables and a reduced energy efficiency target. The thermal resource mix in this scenario will be the same as the base case.

2) **PJM (2) Trended Renewables + Trended Energy Efficiency:** This scenario will be derived by trending the level of existing and under-construction wind and solar

resources in the PJM interconnection queues since 2006. Using a simple linear regression, the level of expected wind/solar will be projected for 2020, 2025 and 2029. Similarly, the level of Energy Efficiency will be trended based on the level of energy efficiency that cleared successive PJM RPM Base Residual Auctions. The energy value of energy efficiency was calculated assuming the same load factor projected in the PJM load forecast report.

3) **PJM (3) Commercial Probability (Natural Gas):** This scenario adds only ISA and FSA[9] natural gas SCT and CC units to meet the higher of the commercial probability[10] or the reserve margin target. ISA/FSA units were selected based on likelihood of their construction given interconnection costs and location (lowest costs of network upgrades expected, zonal congestion, Locational Deliverability Area, etc.). This scenario will retain all the assumptions on renewables and energy efficiency from the PJM (2) scenario.

4) **Nuclear Retirement Sensitivity:** Using PJM (3) scenario, PJM will simulate 10 percent of the nuclear capacity as retired. To protect commercially sensitive information about specific nuclear units, a 10 percent reduction in output will be assumed for each nuclear unit in the PJM footprint.

5) **Economic Case:** Using PJM (3) scenario, if the scenario binds on the CO_2 limit, PJM will run a single, additional simulation in which uneconomic units are removed to identify whether the PJM region still binds on the regional mass-based limit. If the scenario continues to bind, PJM will report the difference in megawatts on a regional level for uneconomic units as a result of implementing a CO_2 price to get under the regional mass limit.

---

[9] Generation developers progress through the various interconnection queue stages as they move closer to construction and commercial operation. Facilities Study Agreement stage precedes the Interconnection Service Agreement stage.

[10] For more information on the methodology PJM used to calculate commercial probability, see page 28 of 2013 PJM Reserve Requirement Study. http://www.pjm.com/~/media/planning/res-adeq/2013-pjm-reserve-requirement-study.ashx. For the 111(d) modeling assumption of commercial probability, PJM applied the calculation methodology described on page 28 to the current PJM Queued resources.