Economic and System Reliability Benefits of the Three Mile Island Generating Station

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1. Executive summary [1]

Three Mile Island Generating Station ("TMI") is an 850 megawatt ("MW") nuclear power plant located near Harrisburg Pennsylvania that provides reliable, round-the-clock energy, enough to power over 750,000 homes. On average, TMI supplies approximately 5% of Pennsylvania's total electricity needs, and does so without emitting any air pollutants or greenhouse gases. TMI's owner, Amergen Energy Company ("Amergen"), a subsidiary of Exelon Corporation, is seeking a 20-year operating extension in license renewal proceedings before the Nuclear Regulatory Commission ("NRC"). This report does not address the merits of license renewal from a technical standpoint. Those issues are properly addressed in the NRC relicensing proceeding. Instead, this report focuses on the economic and system reliability impacts of TMI. From an analytical standpoint, the best way to measure those benefits is to consider what would occur if TMI were shut down.

The economic, system reliability, and environmental benefits provided by TMI include:

- **On average TMI lowers wholesale electricity prices in Pennsylvania by at least $288 million per year** – TMI provides economic benefits to Pennsylvania and to the surrounding region by lowering wholesale market prices for electricity. [2] We conservatively estimate that these benefits average **$288 million** per year in Pennsylvania alone, and **$1.1 billion** per year in all of PJM. [3] Our estimate is based on an empirical model that calculates wholesale market prices in the eastern region of PJM ("PJM East") with and without TMI. The changes in PJM East market clearing prices corresponds to $1.1 billion in lower wholesale energy costs, annually. To estimate the portion of that benefit accruing to Pennsylvania, we multiplied the total benefit by the Pennsylvania utilities' (PECO and PPL) share of total PJM East load. Since the load of the two Pennsylvania utilities represents 27% of total PJM East load, the price reduction benefits accruing to Pennsylvania are $288 million.

- **TMI reduces peak hour electricity prices substantially - $570,000 in a single hour** – We analyzed power flows within PJM and determined that, although TMI is considered to be a PJM East resource, the plant provides significant benefits to other utilities in the western part of the state. Our independent analysis of the reliability impacts of shutting down TMI indicates substantial electricity price increases for electric utilities across Pennsylvania during peak hours. Our analysis indicates that, without TMI, Pennsylvania consumers would likely pay an additional **$570,000** for electricity just in the single peak hour we modeled. [4]

- **In addition to lower electricity prices, TMI annually creates $142 million of economic activity in Pennsylvania and 659 full-time equivalent jobs** – TMI has **507** full-time employees, excluding security staff, [5] and also employs hundreds of temporary

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[1] This report was sponsored by Exelon Corporation. Amergen operates TMI, and is a wholly owned subsidiary of Exelon Corporation.

[2] In addition, shutting down TMI could increase capacity market prices that are determined by the reliability pricing model (RPM) auctions that are conducted by PJM each year. This is a potentially significant impact However, quantifying this impact was beyond the scope of our analysis.

[3] PJM Interconnection LLC, ("PJM") is the independent operator of the electrical transmission system in Pennsylvania and surrounding states. PJM operates the regional wholesale electricity markets, and is responsible for ensuring the reliability of the electrical system.

[4] Power flow analysis based on the 2005 Series, NERC/MMWG Base Case Library, 2006 Summer Final. See Appendix B for further details.

[5] As Three Mile Island also has a large full time security staff, the specific numbers of which are restricted information under the Patriot Act, the overall employment impact, as stated in this section, is necessarily conservative.

contract employees during refueling outages. In addition to the direct benefits the plant provides in terms of lower electric prices, a number of economic impacts accrue from expenditures made by Amergen to operate and maintain the plant. These impacts flow from employee compensation, in-state expenditures on goods and services needed to operate the plant, and local and state property tax payments. Direct economic contributions total **$99 million** annually for Pennsylvania. These economic injections in turn stimulate increased activity elsewhere in Pennsylvania's economy, creating jobs and increasing disposable income. Based on economic impact analysis performed by the Nuclear Energy Institute, the overall annual dollar impacts, including the $99 million direct impact, total approximately **$142** million per year in Pennsylvania. Similarly, TMI creates an estimated 659 full-time equivalent jobs, including the 507 full-time employees at the plant. [6]

The $142 million of economic activity created by TMI does not include the $288 million of benefits from lower electricity prices induced by generation from the plant. Nor does it include the economic benefits that flow from lower electricity prices, which help make Pennsylvania businesses and industries more competitive, thus promoting increased output, additional job creation, and greater disposable income for consumers. Although estimating the magnitude of these impacts was beyond the scope of this paper, they would be substantial.

- **TMI enhances the environment by providing greenhouse gas-free, round-the-clock power equivalent to removing up to 1.3 million cars from the road –** TMI provides significant environmental benefits by reducing the need to generate electricity from fossil fuels, thus reducing greenhouse gas emissions that cause global warming. If TMI were retired from service, the electricity it now provides could not be replaced by generation from other existing carbon-free nuclear plants, which already operate essentially non-stop except for refueling and maintenance outages. Nor could renewable generation replace a significant amount of TMI's power, since intermittent renewable resources such as wind generators cannot produce the round-the-clock baseload output TMI provides.

  As a result, replacing the energy produced by TMI would require increased natural gas-fired or coal-fired generation, producing large quantities of carbon dioxide (CO2), nitrogen oxides (NOx) and sulfur dioxide (SO2). We estimate that, if TMI's output were replaced with increased generation from coal, the annual increase in CO2 emissions would be the equivalent to that of about **1.3 million cars**. Replacement with natural gas generation would cause an annual increase in CO2 emissions equivalent to about **640,000 cars**. Furthermore, in a carbon-constrained future, the value of a large greenhouse gas-free baseload generation resource such as TMI will only be enhanced by the recent Supreme Court rulings, which may hasten the retirement of baseload coal plants.

- **TMI enhances electric reliability in Pennsylvania, significantly decreasing the likelihood of power outages and transmission overloads** – TMI provides critical support to maintain regional electric reliability – i.e. maintenance of uninterrupted electric service and prevention of transmission network overloads. PJM has identified projected overloads of the electrical system within Pennsylvania associated with moving power from PJM West to load centers in PJM East, even assuming continued operation of TMI.[7] Shutting down TMI would accelerate and exacerbate overload conditions on

[6] Again, the total jobs impact for Pennsylvania excludes the security personnel employed at the plant.

[7] PJM 2006 Regional Transmission Expansion Plan, PJM (February 27, 2007), Section 5.10.

several of the transmission facilities PJM has identified as requiring upgrades. PJM is also assessing the need for new "backbone" transmission facilities to move power to the east, the need for which would likely be increased by the retirement of TMI. Construction of a major new transmission facility would be costly, and would face substantial challenges, including the time required to conduct environmental impact assessments, obtain state and local construction permits, and overcome potential local opposition.

1.1. Summary of impacts

Table 1: Three Mile Island's Annual Economic Impacts on the State of Pennsylvania

Direct economic benefit of reduced wholesale electricity prices	
State of Pennsylvania, $ million	$288
PJM East region, $ million	$1,063
Direct economic impacts of plant expenditures	
Full-time, non-security employment	507
Annual direct injections to the state economy, $ million	$99
Employment and expenditure impacts, including multiplier effects	
Total state employment	659
Total state impact, $ million	$142

Note: substantial multiplier impacts would also be expected as a result of reduced wholesale electricity prices. Estimation of those impacts was beyond the scope of this report.

1.2. Outline of this report

Our report and analysis are set forth as follows. Section 2 evaluates the value of TMI to Pennsylvania electricity consumers that is derived from reductions in wholesale market electricity prices and greenhouse gas emissions. Section 3 assesses the benefits of TMI in enhancing the reliability of the electrical system. Section 4 discusses the broader economic impacts of TMI that stem from contributions such as the jobs the plant provides, the purchases of services and equipment made by Amergen to operate the plant, and property taxes paid by Amergen. Together, these impacts ripple through the overall Pennsylvania economy. Moreover, lower electric prices also cause "ripple" effects, because they lower the costs of providing goods and services and increase residential consumers' disposal income.

2. The economic benefits of Three Mile Island electric generation

Each year, Three Mile Island generates about seven million megawatt-hours (MWh) of electricity. This represents about five percent of Pennsylvania's average annual demand and is enough to power over 750,000 homes. The actual quantity of electricity generated each year depends on whether the plant requires refueling, which takes place approximately every two years, or whether it requires other necessary maintenance that cannot be performed during those periodic refueling outages. Like all nuclear plants, TMI has low running costs compared with other types of generation. As a result, the plant operates round-the-clock, providing what is called "baseload" service.

TMI produces highly valuable, low cost electricity for Pennsylvania and the surrounding states that make up PJM. Like all other markets for products and commodities, the electric markets in PJM are based upon simple supply and demand principles. If supply is reduced in the face of growing demand and rising fuel costs, then market prices will increase. In Pennsylvania, nuclear energy is the least expensive means of producing baseload electricity. This means that if TMI is shut down or retired, the generation supply needed to replace TMI would inevitably come from more expensive generating resources (coal, natural gas, or renewable), and this would inevitably lead to higher wholesale and retail electric prices for Pennsylvania consumers and businesses. Thus, at the most basic level, the electricity generated by TMI benefits consumers because electricity prices are lower then they would be without TMI.

2.1. Quantifying the economic benefits of Three Mile Island generation

The PJM day-ahead and real-time energy markets establish wholesale clearing prices for electricity based on supply and demand bids from market participants. These bids determine which generation resources will be used to meet electricity demand at the lowest possible cost, while protecting the transmission system from overload.[8] The price of electricity in any given hour (or fraction of hour) is determined by the price of the generation unit needed to serve the load.[9] Prices rise when demand increases or when the proportion of low-cost generation decreases, because more expensive oil and gas units also need to run to serve customers.

To estimate the economic benefit of TMI's generation, we used historical PJM market data to develop a statistical model that describes the relationship between overall demand in PJM East[10] and prevailing market prices for the period 2005 through 2007. [11] This model estimates how wholesale energy prices change in response to a given change in load, while controlling for changes in natural gas prices.[12]

8 This is known as "security constrained economic dispatch."

9 PJM's markets produce prices on a locational basis. The price-load model uses real-time prices at the Eastern Hub. Details on the modeling are provided in Appendix A.

10 PJM operates the electrical system and centralized power markets across a broad region that extends from the Mid-Atlantic States to the Midwest. PJM East is a subregion that consists largely of the original power pool territories in Pennsylvania, New Jersey and Maryland.

11 Bates White originally developed the model for testimony filed on behalf of the New Jersey Board of Public Utilities regarding the benefits and costs of the proposed Exelon-PSEG Merger. See, IMO The Joint Petition Of Public Service Electric And Gas Company And Exelon Corporation For Approval Of A Change In Control Of Public Service Electric And Gas Company, And Related Authorizations, BPU DOCKET NO. EM05020106 and OAL DOCKET NO. PUC-1874-05, Direct Testimony of Dr. Jonathan A. Lesser, November 26, 2005.

12 See Appendix A for further discussion of the statistical model.

Nuclear generation never sets the market price of energy in PJM, i.e., additional, higher-cost generation is needed to meet total demand each hour. However, low-cost nuclear acts to lower market prices by reducing the need for high-cost generation and allowing the market price to be set by lower-cost units instead. Thus, for purposes of estimating the impacts on market prices, an increase in nuclear or other low-cost baseload output is equivalent to a reduction in load, since both tend to displace the higher-priced marginal generating resource. The load-price model uses this fact, and determines the value of a change in nuclear output (i.e., from the retirement of TMI) by estimating the price impact of an equivalent *increase* in demand. The reason we control for the price of natural gas is that PJM energy prices in peak hours are often set by natural gas-fired generation, and it is in these peak hours that the benefit of baseload nuclear generation is greatest. Controlling for natural gas prices allows the model to produce a better estimate of the price impact of displaced baseload generation.

We estimated market prices for the base case using the statistical model without adjustment. We then estimated market prices with the roughly 800 MW of baseload capacity provided by TMI removed—or rather, equivalently, with 800 MW of additional load.[13] The resulting price changes were then translated into an annual dollar value using average PJM East load by seasonal period.[14] We then derived an overall annual benefit to Pennsylvania based on the fact that Pennsylvania utilities account for 27% of total PJM East load. The calculated annual benefits of TMI output for PJM East and for Pennsylvania are shown in **Table 2**.

Table 2: Estimated Economic Benefit of Three Mile Island Generation

Annual Value to PJM East	Annual Value to Pennsylvania
$1,063,000,000	$288,000,000

These values represent the economic benefit of lower electricity prices made possible by TMI generation and, equivalently, the economic cost of high electric prices that would result if TMI were retired. The Pennsylvania estimate is based on the average PJM-East impact applied to the state proportional to the share of total load represented by the Pennsylvania utility zones, PECO and PPL, which are part of PJM East. The estimates for PJM East and Pennsylvania do not include benefits to utility zones in western Pennsylvania. The independent power flow analysis we performed, which is discussed in Section 3, demonstrates that price impacts in the rest of Pennsylvania could also be substantial. [15]

2.2. Future economic benefits

There are a number of important factors to consider in interpreting the benefit estimates in **Table 2** with respect to the potential retirement or license renewal of TMI. First, it is not clear what generating resources (if any) would replace TMI if it were shut down in 2014. Our statistical model assumes that the energy will be replaced from existing generating resources in Pennsylvania or elsewhere in PJM. Thus, our model estimates the short-term

13 The MW change quantity for each modeled period reflects historical average hourly operation and is less than the 857 MW nameplate capacity.

14 The model distinguishes seasonal periods of two months each: Jan–Feb, Mar–Apr, and so forth. Price impacts are calculated for each of these periods and applied across the corresponding average load.

15 The value estimates also exclude substantial related impacts from the resulting increase in competitiveness of Pennsylvania businesses, and the increase in disposable income of consumers.

adaptive market responses to losing the output of TMI. It does this because those adaptive responses are reflected in the variation of prices and loads over the historical period. Demand spikes, unexpected plant outages, variations in regional imports and exports, transmission constraints, and the associated responses from market participants and the system operator are all reflected in the historical relationship of price and load, and this relationship is captured by the statistical model.[16] Thus, the estimates are likely to be a good indicator of the short-term market impacts.

The long-term dynamic responses to the permanent loss of TMI will tend to reduce the short-term costs we have calculated. The reason for this is that, eventually, the loss of TMI will be compensated for with new resource additions, energy efficiency measures, and so forth. What those long-term responses will be, however, is subject to significant uncertainty with respect to a number of factors that are difficult to predict accurately.

- **Fossil fuel prices**. Higher fossil fuel prices would increase the expected benefits of continued operation of TMI, because the price impact of displacing inefficient fossil generation on the margin would be greater. Conversely, lower fossil fuel prices would reduce the expected benefits from TMI output.

- **Demand growth**. PJM demand is projected to grow at an annual rate of about 2% over the next 10 years. To the extent that there is limited potential for new baseload nuclear or coal-fired generating resources, the proportion of intermediate and peaking natural gas-fired generation capacity in PJM East is likely to increase. This would tend to increase the number of hours when the generation output from TMI would have greater price reduction effects and, thus, greater economic benefits.

- **Environmental regulation**. The recent Supreme Court decisions affirm EPA's responsibility for regulating CO_2 emissions under the Clean Air Act,[17] interpret "new source review" rules under the Clean Air Act,[18] and create the potential for substantially higher fossil-fuel generation cost and premature retirement of coal-fired plants. Any of these developments would tend to increase the economic benefit from TMI output.

On balance, considering both longer-term dynamic responses and the factors listed above, we expect that the price benefits of TMI's generation looking forward would be even greater than the values shown in **Table 2**.

2.3. Longer-term replacement generation

As we have discussed, removing TMI from service (and its capability for round-the-clock power) is essentially equivalent to increasing demand in every hour. Hence, the question of replacement corresponds to the challenge of meeting an even greater increase in electric demand in the future. The PJM 2006 Regional Transmission Expansion Plan (RTEP) identifies some of the factors that contribute to the difficulty of ensuring the reliability of Pennsylvania's power system, even assuming TMI remains in service.[19] These factors include the following:

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16 In Section 3, we discuss impacts of TMI retirement on electrical reliability, and make reference to potential transmission upgrades as one mitigation strategy. The price-load model cannot account for such structural responses, yet, since transmission upgrades would be expensive, and could not compensate completely for the loss of TMI, this fact does not imply any upward bias in the model estimates.

17 Massachusetts v. Environmental Protection Agency, Slip Op No. 05-1120, April 2, 2007.

18 Environmental Defense Corp, v. Duke Energy, Slip Op. No. 05-848, April 2, 2007.

19 PJM 2006 Regional Transmission Expansion Plan, February 2007, 270.

- Increases in power transfers from east to west
- Deactivation/retirement of existing generation resources
- Aging infrastructure
- Interconnection requests for wind generation resources

The RTEP includes a large amount of queued capacity in Pennsylvania from new coal and wind generation. Neither of these sources of power is likely to replace the power currently generated by TMI. While many of the interconnection requests for new coal-fired facilities remain active, the uncertainty and cost implications of potential CO_2 control rules reduce the likelihood that significant new coal generation could serve as a replacement for TMI. It is also unlikely that the entirety of proposed wind generation will be developed. More important, wind power is neither a practical nor a cost-effective replacement for TMI. TMI produces a large volume of low-cost, round-the-clock power—enough to power 750,000 homes. Intermittent wind power, which is dependent on the weather, cannot offer such consistent, reliable power and would need to be supplemented with new fossil-fuel generation within Pennsylvania or increased imports. Additional baseload power would come largely from coal-fired plants, because the other nuclear plants in PJM are already generating at or close to their maximum capability. This means that a shutdown of TMI would lead to significant increases in air pollution emissions, including increased emissions of sulfur dioxide (SO_2) (which are associated with acid rain formation), increased emissions of nitrogen oxides (NOx) (which contribute to smog), and increased emissions of carbon dioxide (CO_2) (a greenhouse gas implicated in global warming). **Table 3** illustrates the estimated increased emissions of these gases from replacing TMI output with an equivalent amount of fossil fuel generation.

Table 3: Increased Annual Emissions from Replacing TMI Generation, by Fuel Type
Short tons of emissions associated with seven million MWh of generation[20]

Fuel	SO_2	NOx	CO_2
Coal	45,500	21,000	7,871,500
Oil	42,000	14,000	5,852,000
Natural Gas	350	5,950	3,972,500

Source: U.S. Environmental Protection Agency, based on data from eGRID 2000

Moreover, as noted previously, because the other greenhouse gas-free nuclear plants are also running at near capacity, they are not a potential source of replacement energy for TMI. To provide some context for the data in **Table 3**, the yearly increase in CO_2 emissions from replacing TMI output with coal-fired generation is roughly equivalent to the annual output of 1.3 million cars.[21]

2.4. Renewable resources

Renewable energy has many virtues and, like nuclear, produces no carbon emissions and reduces exposure to volatile fossil fuel prices. However, renewable resources have some

[20] Emissions rates used for calculation are the U.S. national average rates for electric generation for each fuel type.

[21] Motor vehicle equivalent of CO_2 output is based on U.S. EPA calculations. See http://epa.gov/otaq/climate/420f05004.htm.

limitations. Solar panels do not produce energy when the sun is not shining, and wind turbines do not turn when the wind is not blowing. As a result, an electric system that relies too heavily on these energy sources risks outages or brown-outs when the weather does not cooperate. Moreover, large swings in solar and wind availability can have destabilizing impacts on the transmission system, and this can limit the amounts of these resources that can be interconnected in any one location.

A generation source's ability to consistently produce cost-effective energy is called its "capacity factor." In simple terms, the capacity factor measures the difference between a plant's theoretical ability to produce electricity and the amount of electricity that the source actually produces. Nuclear plants have a high capacity factor because they are baseload plants designed to produce energy on a round-the-clock basis regardless of the weather. In contrast, renewable sources have low capacity factors because they do not run many hours of the year. As an illustration, suppose that a wind turbine could theoretically produce 5 MW of electricity per hour for every hour in a day, or 5×24=120MWh, but in actual operation only produced 30 MWh. The wind turbine would have a 25% capacity factor over the course of that day. In practice, capacity factors are calculated over longer periods, such as an entire year, to capture a resource's average operation over a representative time frame.

Actual operational data show the enormous differences between nuclear plant capacity factors and wind turbines. In 2006, TMI had a capacity factor above 97%, meaning that it actually produced 97% of its theoretical maximum output regardless of weather. By way of comparison, the two wind farms in the Pennsylvania for which generation data are available (totaling 98MW of capacity) had a combined capacity factor of 29% in 2006.[22] The combined capacity factor of the wind farms in the peak demand months of July and August was only 17%. This is fairly typical for wind generation and demonstrates that even a large number of wind turbines could not replace the reliable baseload round-the-clock output of TMI. Unfortunately, the wind often just doesn't blow on the hottest days in July and August.

Solar generation, either photovoltaic or thermal, suffers from a similar problem. Actual operational data are not readily available for solar, but even in areas of the country with the clearest skies, there is no solar generation at night. This lack of predictability means that to support system reliability, intermittent generation sources like wind and solar must be backed up by other generators. This adds to the net cost per MW of capacity and potentially offsets the emissions benefit.

2.5. Peak load impacts – power flow model results

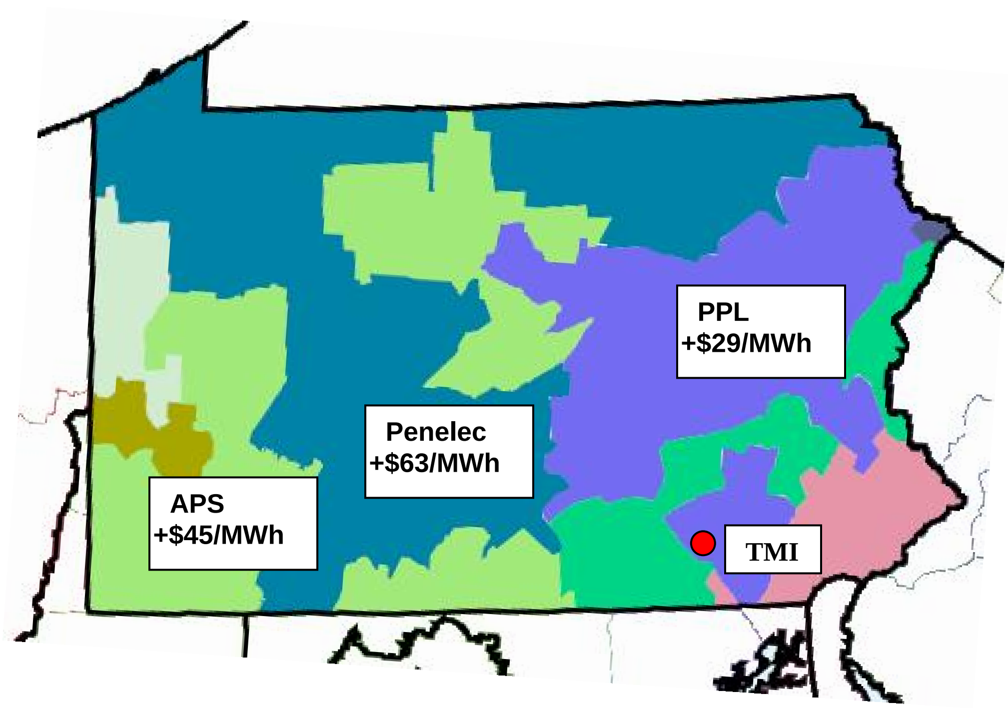
Pennsylvania has 11 electric distribution companies (EDC's): Allegheny Power (West Penn Power), Citizens Electric, Duquesne Light, Penn Power, Met Ed, Penelec, PPL Electric Utilities, PECO Energy, Pike County Light & Power, UGI Utilities, and Wellsboro Electric. All of these provide network transmission and distribution services to Pennsylvania's electricity users. Wholesale power prices vary by EDC zone, according to local demand patterns, generation resources, and the availability of transmission to import and export power. Under peak load conditions, power flows from western Pennsylvania to the east are constrained by limited transmission capacity. To examine peak hour impacts of removing TMI from service, we used a power system simulator to model the power flow and resulting market price effects in each EDC zone under summer peak conditions. The results of this analysis both confirm and complement the statistical load-price analysis presented above. The power flow results confirm that the dollar value impact of losing generation from TMI would

[22] Waymart Wind and Meyersdale Windpower, both located in Pennsylvania. Data source: EIA Form 906 for 2006.

be substantial, and they also illustrate that EDC zone prices across Pennsylvania will be affected by the loss of TMI.

The simulation we performed is based on a snapshot of estimated electrical flows in the PJM system at a single peak hour for summer 2006.[23] We compared the results of a "base case," with TMI operating to the case with TMI removed. The impact on market prices corresponds to an increase in energy costs of $570,000 for Pennsylvania as a whole —just in that single hour. And we estimated the aggregate dollar impact in all of PJM to be $760,000 for that single hour.

Figure 1: Pennsylvania Zone Price Increases



It is important to emphasize again that the power flow analysis examines the effect of eliminating TMI generation at peak system load. Under such conditions, transmission from west to east is operating at maximum capability consistent with reliability limits. In modeling the effect of removing TMI from service, the distribution of impacts between PJM East and western parts of PJM, including western Pennsylvania, depends on assumptions about the extent to which existing power flows to the east are maintained. For instance, significant amounts of power currently flow from western Pennsylvania into PJM East (including eastern Pennsylvania). Because there is limited excess generation locally in the east, a small reduction in imports can have a large impact on market prices, because higher-cost local resources must be used to meet demand on the margin. The specific case we examined assumed that power flows into PJM East would be largely unchanged. Consequently, price effects in the eastern zones, such as PECO, are low, and the impacts in western Pennsylvania are substantial.

[23] The base case power flow data are for the 2006 summer final snapshot from the NERC Multiregional Modeling Working Group (MMWG) model. Further details of the methodology are provided in Appendix B.

In contrast, the statistical model estimates price effects not only for a single peak hour but also for all hours over the three-year historical period, 2005 through 2007. Also, the statistical model only considers impacts on PJM East because the necessary hourly load and price data are readily available and because PJM East is a well-defined wholesale electricity market. The power flow analysis complements the statistical analysis by demonstrating that market price impacts from the loss of TMI would extend throughout Pennsylvania, particularly during peak conditions.

3. Reliability impacts

Electric system reliability essentially measures the likelihood that the lights will go out. The typical standard for electric service in the United States is that the likelihood of a widespread outage should be quite rare—only once in 10 years. This "loss of load expectation" (LOLE)[24] standard is used by transmission system operators such as PJM to determine needed investments in new generation and transmission infrastructure.

Maintaining this "once in 10 years" LOLE requires that the system have excess generation capability, called planning reserves, as well as safety margins and redundancy in the transmission system itself. Additionally, transmission operators rely on plants that are ready to respond on short-notice (called "spinning reserves") and on direct minute-to-minute control (called "automatic generation control" or "AGC") of certain plants already generating power. These tools allow the system operator to match generation to demand every second of every hour and to respond to various contingencies (whether an unexpected plant outage or extreme weather) to ensure the safety and security of the transmission grid. Reductions in excess generation capability erode system reliability.

Baseload power plants play an important role in maintaining system reliability, because they are stable and predictable resources. Moreover, because baseload plants tend to be large, removing such plants from service can have significant adverse impacts on overall system reliability. If a baseload plant is suddenly shut down, it can be difficult to find sufficient replacement power locally. As a result, replacement generation must be imported. This can further strain the transmission grid, especially if that grid is already constrained, as is the case in PJM East.

3.1. Maintaining system reliability in Pennsylvania

Electric system reliability in Pennsylvania is affected by large demand from load centers in the East and intrastate transmission constraints. These two factors reduce reliability because they require the transmission infrastructure to operate close to its operational limits. That, in turn, increases the likelihood of overloads and limits possible responses to unexpected events. The concentration of load in the eastern part of the state, and beyond, in New Jersey and New York, requires large volumes of power to be delivered to a relatively small geographic area. The concentration of population also means it is difficult to build either new power plants or transmission lines, because of local land use planning and siting requirements and community opposition.

PJM's RTEP identifies a number of factors that will continue to reduce system reliability in Pennsylvania and the rest of eastern PJM. These include load growth, increased power exports, generation retirement, and aging infrastructure. These factors magnify the potential adverse reliability impacts associated with removing TMI from service.

3.2. Reliability impacts of shutting down Three Mile Island

Shutting down TMI would significantly reduce the reliability of the electrical system in Pennsylvania and the surrounding PJM region and increase the likelihood of transmission

[24] LOLE is also known as "loss of load probability."

overloads and power outages. Transmission upgrades to address this impact would be expensive and would likely present significant siting and permitting challenges.

PJM has identified the need for new “backbone” transmission in Pennsylvania to address the need to transfer increased power from west to east. PJM projects overloads in three high-voltage transmission circuits in 2019 and 2020—even with TMI continuing to operate. If TMI is retired, the risk of such overloads will be greater and will likely arise much sooner. Moreover, PJM’s assessment of critical reliability issues in Pennsylvania was made prior to the aforementioned Supreme Court decisions that will likely increase emissions control requirements for older plants and lead to regulation of CO_2 as a pollutant under the Clean Air Act. The cumulative impact of these two decisions will be to increase the likelihood of additional accelerated generating plant retirements that may further exacerbate the adverse impacts on system reliability that would result from removing TMI from service. In turn, this will also accelerate the need for the “backbone” transmission system investments to reinforce the power grid.

4. Direct and indirect economic impacts[25]

In addition to the economic and environmental benefits TMI provides in the form of lower wholesale and retail electric prices and reduced levels of air pollution and greenhouse gases, the plant directly benefits the local and state economies through wages paid to employees, expenditures on goods and services, and state and local tax payments. Moreover, lower electric prices reduce costs for manufacturers and other businesses and provide retail consumers with more disposable income that can be invested or spent on goods and services. Thus, both the direct economic injections and the benefits of lower electric prices provided by TMI reverberate throughout the local, state, and national economies.

4.1. Economic impacts and economic benefits

Although it is tempting to equate economic *impacts* with direct economic benefits, the two are very different concepts. Economic impact analysis focuses on the effects of actions and the ways those effects cascade throughout the economy. Thus, when a regulated utility builds a new generating plant, it provides jobs for construction workers, among other things. However, the construction costs will then be paid by the utility's ratepayers. The actual construction doesn't "benefit" ratepayers per se, because they must pay for the construction costs. However, if by building the new generating plant more electricity is supplied at a lower price than would otherwise be available, ratepayers have received an economic benefit in the form of lower prices.

Economic impact analysis is designed to trace all the effects of any action throughout the economy. In general, there is a direct impact—for example, the dollar value of direct expenditures on labor, construction materials, as well as indirect and induced impacts. Indirect impacts include changes in sales, jobs, income, and tax payments in other sectors of the economy. Induced impacts include changes in spending by employees on other goods and services. These impacts reverberate through the economy and result in a *multiplier* effect, in which the total economic impact is a multiple of the direct impact (i.e., the multiplier is always greater than one).

4.2. Economic impacts of Three Mile Island

The economic impact estimates we present are based on data made available by Amergen for 2007, in aggregated form. The scope of this analysis did not allow for a detailed economic impact assessment, which typically involves identification and classification of a large amount of cost accounting data and the use of specialized economic impact assessment software and associated economic and demographic databases. Instead, we have developed context around the current available data by making reference to a 2005 report that employed an input-output modeling framework to estimate both direct and indirect economic impacts from the operation of TMI.[26] For instance, we assume that Pennsylvania's share of total plant expenditures has not changed materially since 2004. This is a reasonable assumption because virtually all employment at the plant is local, and goods and services not related to specialized nuclear purposes are likely to be provided

25 We gratefully acknowledge the contributions provided by Professor Anderson for this section of the report.

26 Nuclear Energy Institute, "Economic Benefits of Three Mile Island Unit 1," October 2005 ("NEI Report"),

most economically from the local economy. Amergen has confirmed that these are reasonable assumptions for 2007 data relative to 2004.

4.3. Employment

TMI 1 is located near Harrisburg, Pennsylvania, which is a city of about 49,000. The plant lies in Dauphin County, which has a population of about 123,000.

TMI is a large employer; it has 507 full-time employees ("FTEs") (excluding security staff). Of Pennsylvania's roughly 303,333 business establishments, only about 884 employ 500 or more people. Within Dauphin County, only 28 establishments have over 500 employees. Relative to manufacturing and related industries, TMI makes up roughly 3% of county employment.[27]

Of the 507 FTEs, about 40%, or approximately 200 plant workers live within Dauphin County itself, and virtually all the remaining employees live in other Pennsylvania counties. TMI also employs temporary contract workers during refueling periods that occur roughly every two years. Contract employment over a typical 61-day refueling and maintenance period averages 373, and peak employment reaches 900.[28]

4.4. Direct economic impacts

Direct economic impacts are those arising from direct payments, including employee compensation, expenditures on goods and services, and tax payments. These direct injections to the Pennsylvania economy are summarized in **Table 4**, below.

Table 4: Three Mile Island Direct Economic Injections

$ millions	2006	Annual Avg	PA Share
Total FTE compensation: wages, salaries and benefits.	$80.1	$80.1	$79.3
Total non-fuel outage expenditures (every 2 years)	$33.5	$16.8	$3.8
All other expenditures, excluding fuel	$64.3	$64.3	$14.7
Property tax	$0.6	$0.6	$0.6
State Taxes	$0.9	$0.9	$0.9
Total direct injections to the economy	**$179.4**	**$162.7**	**$99.4**

Source: Amergen; PA shares based on ratios reported in the NEI Report.

FTE compensation is the main economic impact for Pennsylvania, and of course it has even greater significance for Dauphin County, where most employees live. The Pennsylvania share of total compensation is 99% of the total for TMI, based on the proportion for 2004 in the NEI report. Expenditures related to refueling outages, which occur every two years, are shown as a total in the 2006 column and as an annual average in the next column. Annual plant totals for outage costs and all other expenditures (excluding fuel) are translated into impacts for Pennsylvania by applying the proportion of expenditures from the NEI report.

[27] Relative to county-level census data for manufacturing, construction, and utilities.

[28] Data made available by Amergen.

4.5. Multiplier impacts

In addition to the direct economic impacts estimated in **Table 4**, the multiplier impacts that flow throughout the Pennsylvania economy represent significant additional economic activity that results from the operation of TMI. It is not possible to assess the expected magnitude of the overall multiplier applicable in this case without a full-blown economic impact analysis. The size of the aggregate multiplier will depend on a variety of factors, including state income tax rates, and the extent to which various local industries are affected by the indirect and induced impacts. With respect to jobs and labor income, the NEI report indicates effective multipliers of 1.30 and 1.23, respectively. Applying only these values would increase the total impact from the operation of TMI to 659 jobs and $142 million of annual economic activity created in Pennsylvania. This does not consider the additional multiplier effects that are likely to result from the generation output of TMI and the associated reduction in market energy prices.

About the Authors

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Appendix A – Generation Benefits Analysis

Round-the-clock baseload power from TMI lowers wholesale energy prices by reducing the need for higher-cost resources that, in the absence of the plant's output, would set the marginal price for the PJM market. To assess the magnitude of this economic benefit, which is also an estimate of the economic cost of retiring TMI from service, a statistical analysis was conducted to estimate the relationship between changes in baseload capacity and changes in real-time energy prices in the PJM-East region. That statistical analysis, the resulting model, and the underlying model logic are described in this appendix.

Fundamental to the analysis is the fact that PJM is a centrally dispatched electrical system in which generation resources are deployed in economic merit order to serve load with the least cost units dispatched first. Real-time energy prices are determined by the last generation unit required to meet demand, reflective also of system transmission constraints. Also fundamental to the analysis is the fact that TMI is a baseload generation unit. This means it operates at high output at all hours. TMI's output displaces the need for higher cost generation resources at the margin, and this tends to lower market-clearing prices. The fact that the plant operates at stable output levels over all hours makes it possible to model the price impact of a change in TMI output as an equivalent change in load (i.e., electrical demand).

Using readily available historical market data (hour loads, real-time clearing prices, and daily natural gas prices), we constructed a statistical model of the relationship between load and energy prices in PJM East. This relationship was then used to estimate the effect on prices of removing TMI from service.

For an arbitrary, short period of time, the availability of generation to serve load in a given area and the variable cost of such resources can be considered fixed. In a system with economic dispatch and no transmission constraints, this amounts to a fixed supply curve, such that the market-clearing price is determined by the level of total demand. This is illustrated in **Figure A-1**, where a load of 8,500 MW results in a clearing price of about $50/MWh.

Figure A-1: Illustrative Load-Price Relationship

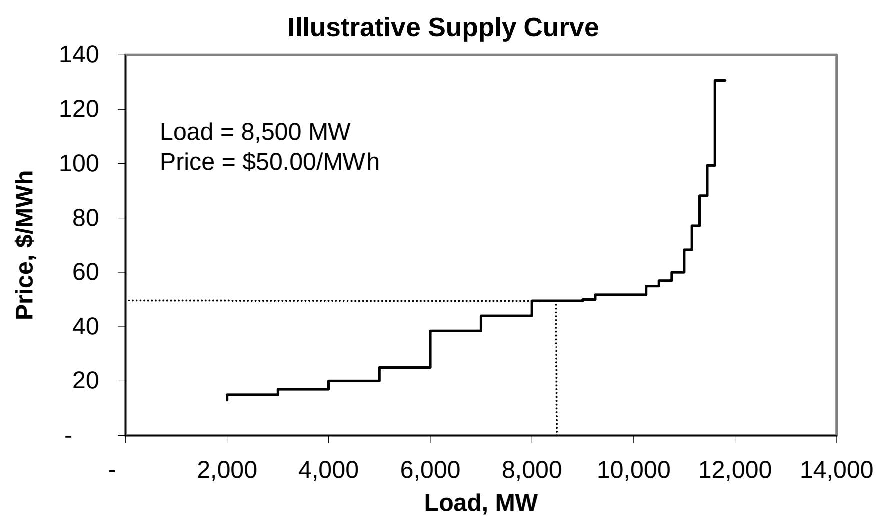
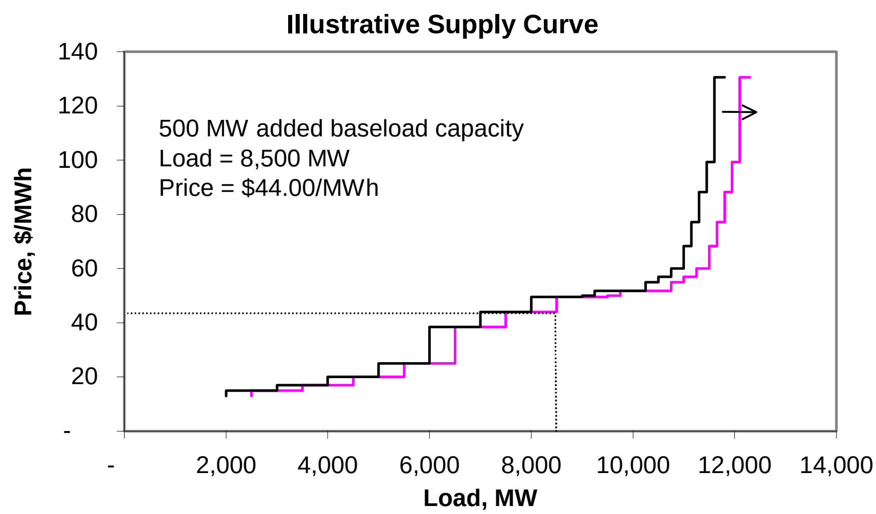


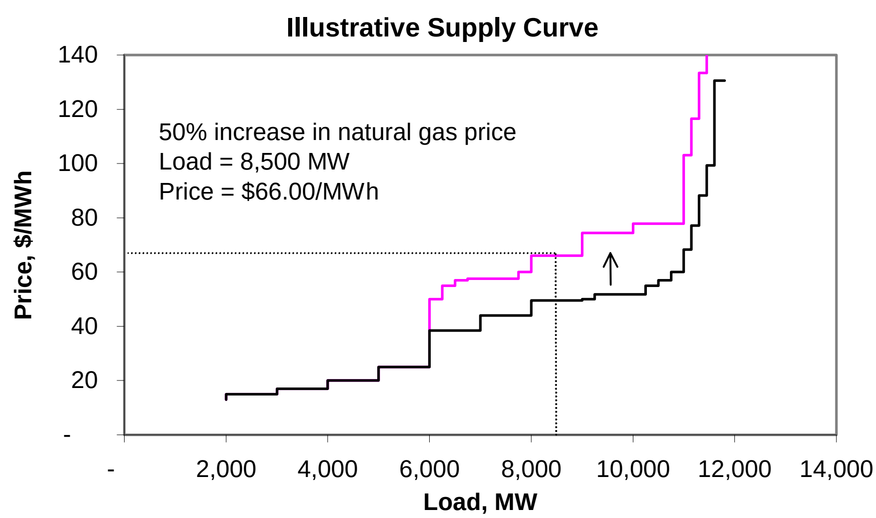
Figure A-2 illustrates what happens when baseload generation increases. The supply curve shifts to the right, eliminating the need for the $50.00/MWh resource to run in order to meet load, and thereby allowing the market-clearing price to be set by the next lowest cost resource at $44.00/MWh.

Figure A-2: Increased Baseload Generation



The shape of the supply curve is also sensitive to changes in fuel prices. The primary source of price volatility is the natural gas commodity price. **Figure A-3** illustrates the impact on the supply curve of a 50% increase in natural gas prices.

Figure A-3: Natural Gas Price Increase



The statistical analysis of PJM East load and real-time energy prices accounts for the illustrated changes in the shape of the supply curve, stratifies the data into ranges of gas prices, and estimates separate price-load functions for each grouping. This is done is to remove gas prices as an explanatory variable and isolate changes in load (demand) as the explanatory variable determining price variation. The purpose is not to forecast electricity prices, but to examine the impact of an increase in baseload generation on energy prices.

This analytical approach offers some advantages over a structural model, particularly in reflecting market dynamics. For example, in a structural model, shocks to the system, such as unforced generation outages, must be either ignored or specified as probabilities. Other factors, such as the ability of some plants to operate beyond nameplate capacity for short periods, or other dynamic responses by market participants, are difficult to incorporate in structural models. However, information about such influences is implicit in the market data, and the statistical approach can account for it as a matter of course.

PJM Price-Load Model Specification

Hourly loads and hourly real-time locational marginal prices (LMPs) for PJM-East were obtained from PJM for the 36-month period January 2005 through December 2007. Daily weighted-average natural gas spot prices at Henry Hub were obtained for the same period. The 36-month period was selected to be long enough to encompass sufficient variation to produce meaningful statistical results, while not being so long as to invalidate the assumption of a reasonably stable generation supply curve.

The statistical modeling parses the year into bimonthly groups. This accounts for seasonal differences in capacity availability. The load and LMP data were further parsed into subsets of the bimonthly groupings based on ranges of historical natural gas prices.

Table A-1 shows the parsed subgroups. A total of 18 subgroups were identified.

Table A-1: Regression Subgroups

Bimonthly Group	Gas Price Range ($/mmBTU)	Hours in Subgroup
January–February	Up to $6.50	1824
	$6.50 to $8.00	1200
	Above $8.00	1224
March–April	Up to $7.00	1560
	$7.00 to $7.50	2040
	Above $7.50	792
May–June	Up to $6.50	1632
	$6.50 to $7.50	1680
	Above $7.50	1080
July–August	Up to $6.50	1872
	$6.50 to $7.50	1176
	Above $7.50	1416
September–October	Up to $6.00	1440
	$6.00 to $8.00	1488
	Above $8.00	1464
November–December	Up to $7.00	960
	$7.00 to $7.50	1632
	Above $7.50	1800

Regressions were then run for each of the subgroups, using the log-linear functional form shown below, where LMP is taken to be the load-weighted average price,[29] and *Load* is the hourly PJM-East load divided by 1,000.[30]

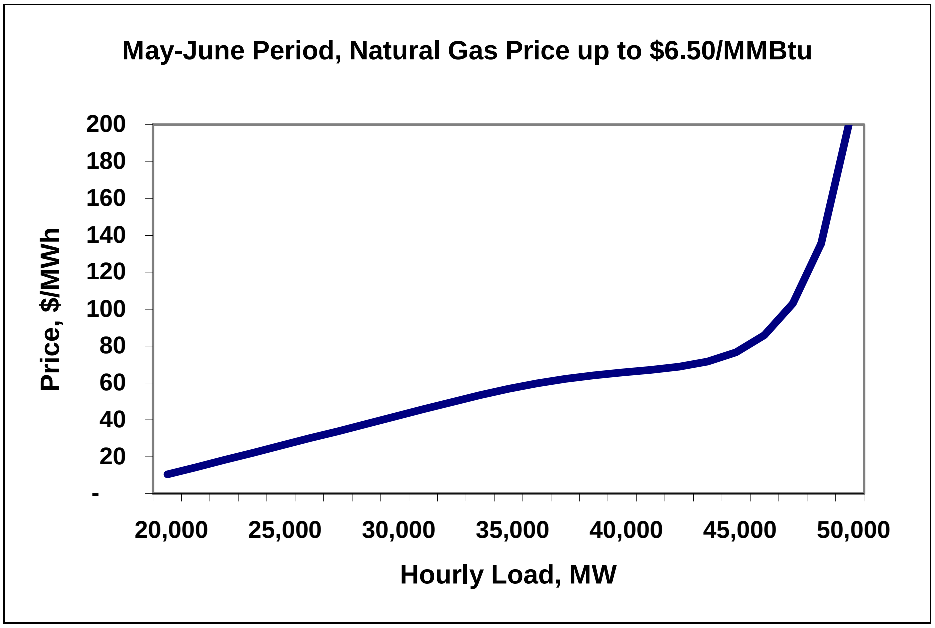
$$\ln(LMP) = \alpha + \beta_1 Load + \beta_2 Load^2 + \beta_3 Load^3 + \beta_4 Load^4 + \beta_5 Load^5$$

The incorporation of the powers of load allows the estimated price curve to reflect the shape of the underlying, structural, cost-based supply curve. For PJM East, the supply curve for a given period is generally characterized by (1) a low and rising shape (i.e., low price) for lower levels of demand (corresponding to supply from baseload nuclear and coal generation), (2) a middle plateau (corresponding to intermediate fossil fuel generation), and (3) a sharp rise at high loads (corresponding to expensive, peaking resources). **Figure A-4** graphs the price-load function based on the regression results for the first May-June subgroup itemized in **Table A-1**. The X-axis shows the approximate range of actual load during the relevant periods (May and June of 2005, 2006, and 2007) when the price of natural gas was less than or equal to $6.00/MMBtu.

[29] Using the log of price in the regressions restricts the estimated prices to positive values. This is a commonly applied technique, although negative hourly LMPs occasionally occur. In these cases, the previous hour's LMP is used.

[30] The use of the divisor 1,000 prevents the power variables from exploding beyond the significant digit capability of Microsoft Excel, which was used to estimate the regressions.

Figure A-4: Example Estimated Price Curve



A reference for each bimonthly group was established first, representing the status quo, i.e., TMI output at actual historical levels. This reference was the base case load-weighted energy price for each sub-period.

The alternative case, with TMI removed from service, was then examined. Hourly loads for each estimation period were *raised* by an amount corresponding to the average historical level of TMI in the given period. For instance, the load adjustment for the January-February period was 854 MW each hour. This corresponds to the average hourly output of TMI for that period over the past five years. Weighted-average energy prices were again calculated for each sub-period, with loads adjusted to reflect the retirement of TMI.

The annual dollar benefit for PJM-East from operation of TMI were then calculated as the average price change times load in each sub-period, summed and adjusted to an annualized value. Annual dollar benefits for Pennsylvania were calculated according to the state's share of PJM-East load. The results of the analysis are summarized in **Table A-2**, below.

Table A-2: Summary Results of Benefits Estimation

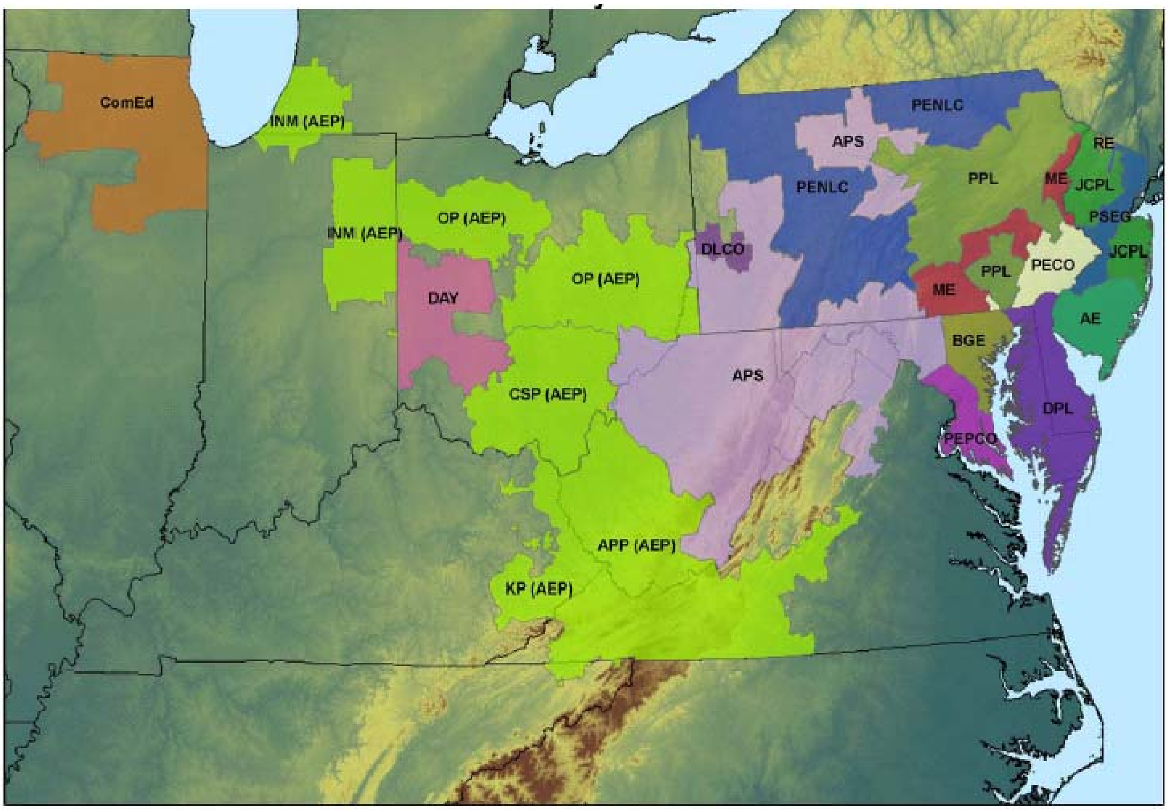
Model Sub-period	Estimated Increase in Average Electricity Cost, $/MWh	PJM-East Load, GWh, Period Average	Benefit of TMI Generation, $000s
Jan-Feb	3.60	48,248	173,489
Mar-Apr	3.02	44,080	133,024
May-Jun	3.13	47,020	147,230
Jul-Aug	5.02	58,156	291,848
Sep-Oct	3.58	45,785	163,765
Nov-Dec	3.30	46,491	153,627
Aggregate	**3.67**		
Estimated Total Annual Value, PJM-East, $000s			**$1,062,983**

PECO and PPL retail sales, 2006 (plus 4% losses)	76,788
% of total PJM-East load	27%
Proportional benefit assigned to PA, $000s	**$287,525**

Appendix B – Independent Power Flow Analysis

Bates White conducted an independent power flow analysis to simulate the LMP impact of retiring the TMI nuclear power plant. The results of our study indicate a total dollar impact in Pennsylvania of approximately $570,000 for a single summer peak hour modeled.

Map of PJM Control Areas



Modeled Areas

- Entire PJM control areas excluding Rockland Electric (RECO) were modeled as OPF control
  - These are PJM500, JCPL, PSEG, AE, PECO, METED, DPL, PPL, PEPCO, BGE, PENELEC, APS, AEP, DAY, DLCO, VAP, UGI, IPRV, and NI (total 19 control areas)
  - Control areas in PA: METED, PPL, PECO, PENELEC, APS, DLCO, and UGI (total 7 control areas)
- All the other areas were modeled as Participant AGC control

Software

PowerWorld Simulator Optimal Power Flow (OPF) and Security-Constrained Optimal Power Flow (SCOPF) software was used to simulate the LMP impact of TMI nuclear power plant retirement.

Load Flow Case

- Base Case: 2005 NERC/MMWG Base Case modeling 2006 summer peak condition
- Change Case: Base Case without TMI nuclear power plant
  - To compensate the TMI unavailability, METED correspondingly decreased exports to and increased imports from other PJM control areas to make up the demand/supply imbalance

METED Area Transaction MW Amount

To Area	MW Export (Base Case)	MW Export (Change Case)	Difference (MW)
PJM500	-716.7	-720	3.3
PENELEC	47.5	40	7.5
JCPL	961	960	1
PPL	-167.6	-390	222.4
APS	44.9	-500	544.9
Total	**169.1**	**-610**	**779.1**

TMI retirement increases the import power flows to METED control area to make up the supply/demand imbalance caused by TMI unavailability.

Independent Power Flow Analysis

An optimal power flow (OPF) analysis simulates economic dispatch while taking account of transmission constraints, i.e., it simultaneously minimizes the total generation cost necessary to meet the control area demand while maintaining the security of the transmission system by ensuring that no limits are violated in a power transfer. Broadly speaking, the production cost is the sum of each unit's generation costs, considering that system security requires running each generating unit within a limited range. An OPF analysis minimizes the production cost function, taking into account physical equality constraints such as generator voltage set points and inequality constraints such as transmission flow limits. An OPF analysis determines the marginal costs of power at each bus in the system (i.e., Locational Marginal Price or LMP) as well as marginal costs of enforcing facility limits such as transmission lines.

Security-constrained optimal power flow (SCOPF) analysis simulates transmission-constrained economic dispatch while taking account of contingency conditions. In order to ensure power system reliability, i.e., with power systems operating such that system overloads do not occur (either in real time or under probabilistic contingency conditions), the resulting power transfer should not overload the power system during or after an occurrence of contingencies, as defined in accordance with the comprehensive reliability criteria established by the NERC. Contingencies can be either simple (such as an outage of a single transmission line or a generator, e.g., N-1 contingency) or complex (such as the simultaneous loss of multiple transmission lines and/or generators, e.g., N-2 contingency). A list of contingencies and monitored elements is defined as follows:

- Monitored elements: All OPF control area lines and transformers above 230 kV are monitored
  - These control areas are PJM500, JCPL, PSEG, AE, PECO, METED, DPL, PPL, PEPCO, BGE, PENELEC, APS, AEP, DAY, DLCO, VAP, UGI, IPRV, and NI (total 19 control areas)
- Contingency elements: Pennsylvania utility control area lines and transformers above 230 kV are simulated to be out-of-service one at a time (N-1 Contingency)
  - These control areas are METED, PPL, PECO, PENELEC, APS, DLCO, and UGI (total 7 control areas)

SCOPF LMP Results

SCOPF LMP results are shown below. For example, in 2006 summer peak condition, APS, PENELEC, and PPL areas average LMP price increases of $45/MWh, $63/MWh, and $29/MWh, respectively.

Area Name	Change Case LMP ($/MWh)	Base Case LMP ($/MWh)	Difference ($/MWh)
DLCO	18	18	-
AE	103	103	0
METED	111	111	0
PJM500	78	78	(0)
UGI	34	34	0
DP&L	121	121	-
IPRV	55	55	-
APS	**66**	**21**	**45**
JCPL	139	139	0
PENELEC	**138**	**75**	**63**
PPL	**90**	**61**	**29**
PECO	127	127	(0)
VAP	98	98	-
BGE	128	128	(0)
NI	74	74	-
DPL	113	113	-
AEP	54	54	-
PEPCO	137	137	0
PSEG	89	89	0

SCOPF LMP Change Impact

The price impact of TMI retirement could be over $750,000 for PJM control areas during a summer peak hour in 2006.

Area Name	LMP Change ($/MWh)	Load (MW)	LMP Impact ($/hour)
DLCO	-	2,765	-
AE	0	2,711	27
METED	0	2,665	160
PJM500	(0)	-	-
UGI	0	174	7
DP&L	-	4,054	-
IPRV	-		-
APS	45	8,610	390,980
JCPL	0	6,156	123
PENELEC	63	2,738	172,200
PPL	29	6,768	194,589
PECO	(0)	8,325	(583)
VAP	-	18,197	-
BGE	(0)	6,894	(483)
NI	-	22,675	-
DPL	-	3,557	-
AEP	-	23,872	-
PEPCO	0	6,523	261
PSEG	0	10,519	105
Total			**757,387**

Pennsylvania Price Impact

The price impact of TMI retirement could be approximately $570,000 for the state of Pennsylvania during a summer peak hour in 2006.[31]

Area Name	LMP Change ($/MWh)	Load (MW)	LMP Impact ($/hour)
DLCO	-	2,765	-
METED	0	2,665	160
UGI	0	174	7
APS	45	4,477[32]	203,301
PENELEC	63	2,738	172,200
PPL	29	6,768	194,589
PECO	(0)	8,325	(583)
Total			**569,674**

31 Modeled control areas in Pennsylvania are as follows: METED, PPL, PECO, PENELEC, APS, DLCO, and UGI (total 7 control areas).

32 The amount represents Pennsylvania portion of the APS load MW.