The Cost of Alternative Energy Portfolio Standards in Pennsylvania

Seth A. Blumsack, Andrew N. Kleit, and Babatunde Idrisu

John and Willie Leone Family Department of Energy and Mineral Engineering

The Pennsylvania State University

Contact Author: Andrew N. Kleit, ANK1@psu.edu; 814-865-0711

October 2011

The views expressed herein are solely those of the authors, and not necessarily those of the Pennsylvania State University.

Executive Summary

The Pennsylvania State University has been asked, by Representative Robert Godshall, Chair of the Consumer Affairs Committee in the Pennsylvania House of Representatives, to study the costs associated with Pennsylvania's Alternative Energy Portfolio Standard (AEPS). The request came to the Pennsylvania State University on December 16, 2010, and the study was conducted between January 2011 and October 2011. The study was undertaken by researchers in the John and Willie Leone Family Department of Energy and Mineral Engineering, and was funded internally by the Pennsylvania State University through the College of Earth and Mineral Sciences. The analysis and opinions herein are those of the study's investigators, and not of the Pennsylvania State University or Representative Godshall.

The study request asked that we focus on the costs associated with Pennsylvania's AEPS. While one purpose of AEPS is to reduce harmful air emissions associated with electricity generation in Pennsylvania, a discussion of these benefits is beyond the scope of the requested study. This study is designed to provide the general public in Pennsylvania with information concerning the costs of implementing AEPS and neither endorses nor opposes the AEPS itself.

The tasks of the study are as follows:

1. We discuss the structure of the Pennsylvania AEPS and briefly compare it to similar mandates in surrounding states;
2. We provide an overview of technologies other than wind and photovoltaic energy that qualify as alternative energy sources under the AEPS;
3. We discuss the costs of expanding wind energy in Pennsylvania to meet AEPS goals;
4. We discuss the costs of photovoltaic energy in Pennsylvania to meet AEPS goals.

The Pennsylvania AEPS specifies two categories or "Tiers" of alternative generation resources that electric energy suppliers can use to fulfill their mandated requirement. While there are a large number of generation technologies that can be used to fill AEPS requirements in each Tier, many of these technologies do not appear to impose significant costs on Pennsylvania ratepayers. In this report, we focus primarily on wind and photovoltaic energy, as these will likely represent the bulk of the investment induced by the AEPS. Photovoltaic electricity generation also has a specific mandate or "carve-out" within the AEPS.

We estimate the costs associated with AEPS by building long-run supply curves for future renewable energy development. Estimation of the costs of AEPS may be useful in Pennsylvania, since the compliance costs do not appear as a specific line item on customer bills. In Pennsylvania, the electric distribution utility is generally responsible for meeting AEPS mandates within its service territory. An exception is for those customers who have chosen an alternative supplier under Pennsylvania's electricity deregulation law. A customer's generation supplier is, in these cases, responsible for procuring or generating sufficient qualifying electricity to meet the percentage mandates for their generation load. The consumer costs of AEPS are rolled into the generation portion of a customer's electricity bill, and are generally not separated out as line items.

The results of our analysis can be summarized in the following points. We have found that the costs of AEPS to Pennsylvania ratepayers are likely influenced by a relatively small number of factors.

First, Pennsylvania is a net exporter of alternative energy credits (AECs) to other states with similar alternative energy mandates. Thus, Pennsylvania generating companies produce more credits than are needed to satisfy the AEPS.

Second, sufficient Tier II resources appear to exist to allow Pennsylvania electricity retailers to meet requirements under AEPS for the remaining life of the program. Our analysis of Tier I resources suggest that wind and photovoltaic energy (due to the photovoltaic carve-out) will likely be the primary drivers of AEPS costs to Pennsylvania consumers going forward.

Third, the relative contribution of wind energy to the overall costs of AEPS has been relatively low to date, as high-quality wind sites can produce energy at costs that are very nearly competitive with conventional generation in the PJM market. Unfortunately, the supply of high-quality wind sites in Pennsylvania is limited. The future cost of wind energy investments in Pennsylvania under AEPS may increase as generation companies seek to develop lower-quality (higher cost) resources.

Fourth, the costs associated with the photovoltaic carve-out are substantial, at current market prices of photovoltaic modules. Depending on the relevant assumption about the rate of cost declines in photovoltaic energy, we estimate that the costs associated with AEPS could be cut on the order of to 25 to 30 percent if the photovoltaic carve-out were eliminated and electricity retailers filled that portion of the Tier I requirement with wind energy.

Table of Contents

I. Introduction to Pennsylvania's Electricity Market

Pennsylvania is one of the nation's largest producers of electric power, and the leading exporter of electric power to other states. In 2010, Pennsylvania exported approximately one-third of its electricity to surrounding states. The size of Pennsylvania's electricity retailing sector is more than $14 billion, or almost 5 percent of the value of all U.S. electricity sales.[1] The electricity industry is also a major provider of jobs in Pennsylvania, employing more than 16,000 people across the Commonwealth.[2]

All of Pennsylvania's investor-owned utilities, and many of Pennsylvania's municipally-owned and cooperative utilities, participate in a regional wholesale market for electricity operated by PJM Interconnection. PJM is the Regional Transmission Organization for a region covering all or parts of thirteen states and the District of Columbia. PJM's territory covers much of the Mid-Atlantic region and extends as far west as Chicago. PJM dispatches generating plants within its footprint and manages the transmission grid to ensure reliability and non-discriminatory access.

The majority of electricity generated in Pennsylvania is produced by the burning of fossil fuels, particularly coal. While coal accounts for less than half of Pennsylvania's installed capacity base (see Figure 1.1), it produces over half of the electric energy generated in the Commonwealth (see Figure 1.2). Over 20 percent of electric generation capacity is natural gas fired, but these plants are used less intensively than coal or nuclear plants in Pennsylvania. As development increases from the Marcellus shale and additional environmental regulations are enacted that increase the cost of generating electricity with coal, the balance between coal and natural gas generation can be expected to shift somewhat in Pennsylvania. Even so, the Commonwealth will likely have a fossil-intensive generation mix for the foreseeable future.

[1] U.S. Energy Information Administration, State Electricity Profiles, http://www.eia.gov/cneaf/electricity/st_profiles/pennsylvania.html.
[2] J. Apt, S. Blumsack, L.B. Lave, "Competitive Energy Options for Pennsylvania," report for the Team Pennsylvania Foundation, 2007.

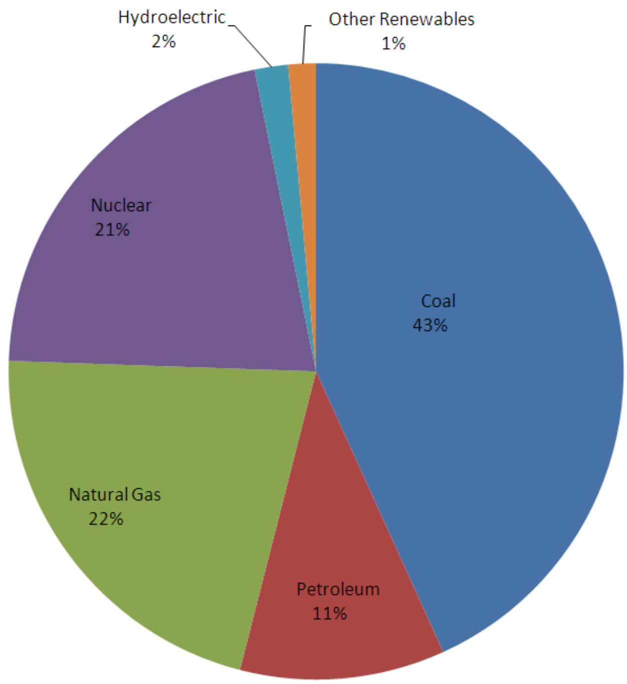


Figure 1.1. Installed capacity mix for electric generation in Pennsylvania

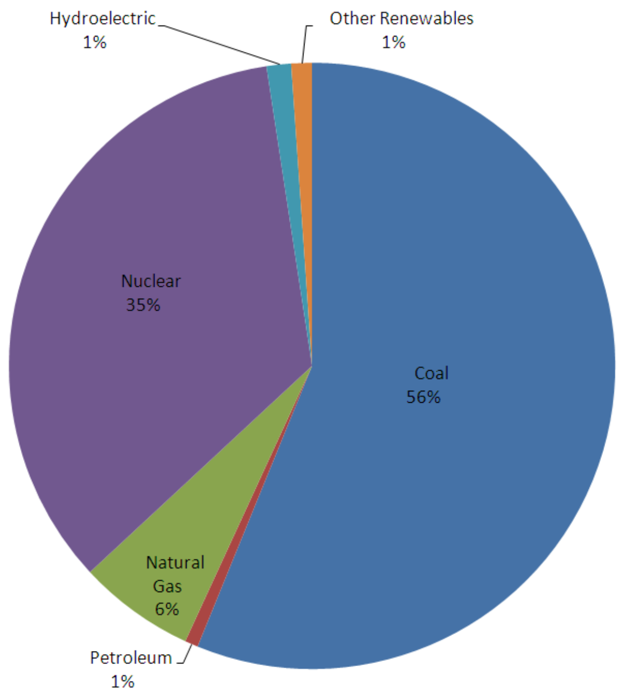


Figure 1.2. Fuel mix for electric production in Pennsylvania

While electricity is the life-blood of any modern day economy, the generation of electricity with fossil fuels has important associated negative externalities through air emissions of carbon dioxide, oxides of sulfur and nitrogen, mercury, fine particulates and other constituents. These air emissions have been estimated to carry significant social costs.[3] To address the environmental impacts associated with electricity production, like many other states, Pennsylvania has adopted an Alternative Energy Portfolio Standard (AEPS). The AEPS is similar to portfolio standards developed in other states but does not strictly focus on renewable energy.

As we discuss in the following sections of the report, many of the technologies promoted by Pennsylvania's AEPS produce energy at average prices or "levelized cost of energy" higher than those prevailing in the PJM market. Thus, Pennsylvania's AEPS provides incentives or subsidies to firms that produce electricity using alternative technologies. To the extent that any such standard like the AEPS is binding upon producers, it will thus increase costs to consumers. The task of this report is to assess the cost of the AEPS standards to Pennsylvania ratepayers.

It is important to understand the context in which the AEPS has been enacted. Pennsylvania has engaged in electricity restructuring at both the retail and wholesale level. Companies that generate electricity no longer do so at rates regulated by the Pennsylvania public utility commission. Rather, they receive the prices they can gain on the free market. Generation firms can sell electricity into spot markets run by PJM, or they can contract bilaterally at whatever price the market will bear. PJM has reported that 85 percent of electricity sales in its territory occur through long-term bilateral contracts.[4]

In Section II we present various sources of electricity that are discussed in the Pennsylvania AEPS legislation. In Section III we examine the details of the AEPS standard, as well as renewable portfolio standards in other states. In Section IV we discuss the importance of interest rates in our calculations. In Section V we derive a supply curve for photovoltaic power in Pennsylvania. In Section VI we derive a supply curve for wind power in Pennsylvania. In Section VII we tie Section III, IV, V, and VI together to create an estimate of the costs of the Pennsylvania AEPS program. Section VIII contains a qualitative discussion of the impact of AEPS standards on private investment in other sources of electricity and on the reliability of electricity markets. Section IX contains our conclusions.

II. The Pennsylvania AEPS Program

Pennsylvania's AEPS targets can be met using a variety of supply resources. These resources are typically believed to be more environmentally benign than fossil-fired power

[3] See, for example, Pope, C. A., 3rd, R. T. Burnett, M. J. Thun, E. E. Calle, D. Krewski, K. Ito and G. D. Thurston. 2002. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. Jama. Vol. 287 (9): 1132-41. A recent study of the life-cycle environmental impacts of electricity production in Pennsylvania suggests that over 80 percent of Pennsylvania's electric-sector greenhouse-gas emissions are attributable to the combustion of coal. See S. Blumsack, P. Jaramillo, W.M. Griffin, H.S. Matthews, "A Life Cycle Greenhouse Gas Emission Inventory for Pennsylvania Electricity Production," report for the Pennsylvania Department of Environmental Protection, 2009.

[4] Apt, et al., *supra*, 2007.

generation, but have higher costs and are thus economically uncompetitive without a mix of federal and state subsidies or incentives. The economic justification for programs such as AEPS is to correct some of the negative externalities associated with conventional fossil generation (primarily air emissions) through the provision of mandates and incentives for (mostly) non-fossil sources. Here we discuss some of the technologies covered under the AEPS.

A. Photovoltaic Energy

Solar energy radiates from the sun to the earth's surface. Utilization of solar energy for electricity production typically uses either photovoltaic or thermal technologies, both of which are qualifying technologies under the AEPS. The solar thermal method uses the energy from the sun to directly heat water, creating steam to power a turbine. In this way, solar thermal electricity production is no different than conventional power production, except that solar radiation is used for fuel. Solar thermal energy may also be used at a smaller scale to heat water for residential or commercial use. In this configuration, solar collectors on a roof of a building absorb the sun's rays and heats water flowing through the collector to be used within a house or business. Photovoltaic systems convert the sun's energy directly into electricity. As shown in Figure 1.3, the electricity produced by solar photovoltaic panels is direct current electricity and must be inverted to alternating current electricity at the proper voltage prior to feeding into the electric transmission grid.

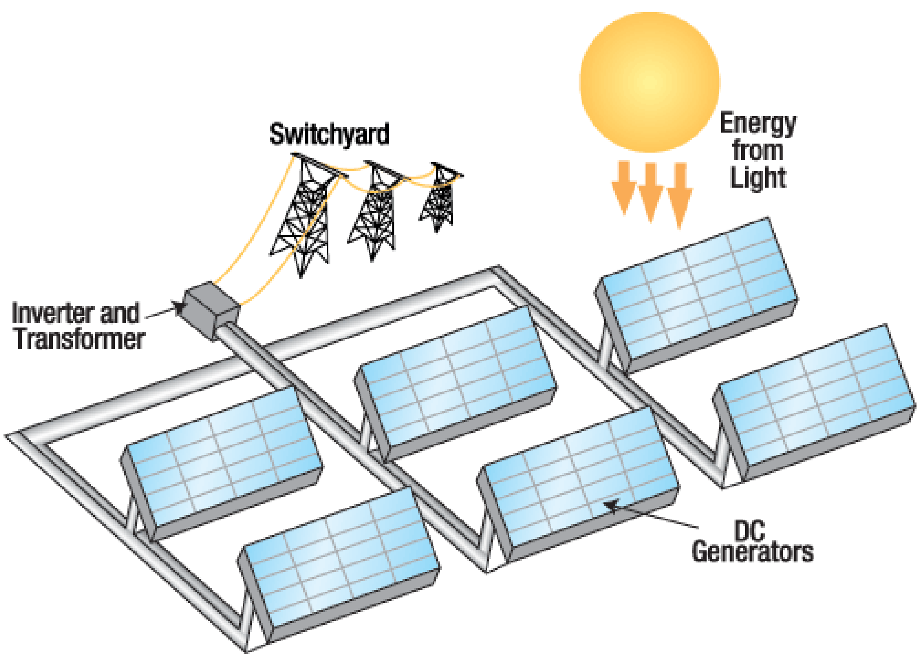


Figure 1.3: Utility Photovoltaic Power System Diagram (Source: Tennessee Valley Authority)

B. Wind Energy

Wind is produced by cool air replacing rising hot air due to variations in the sun's radiation on the earth's surface. Wind has kinetic energy while in motion; the role of the wind turbine is to convert this kinetic energy to mechanical and electrical energy. As seen in Figure 1.4, a wind turbine is made up of a rotor with multiple blades. Inside the enclosure or "nacelle" is the turbine's drivetrain and gearbox along with the generator that produces electrical energy.

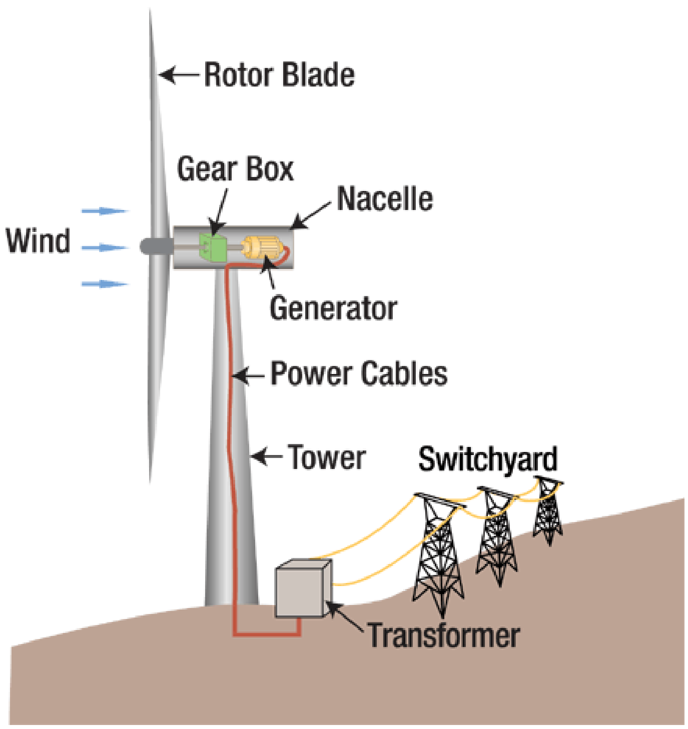


Figure 1.4 Wind Turbine Diagram (Source: Tennessee Valley Authority)

Installments of multiple wind turbines or "wind farms" can be placed both onshore and offshore, depending on resource availability, quality and costs. Utility-scale wind turbines typically range in height from 80 to 100 meters from the ground to the hub, and are rated to produce hundreds of kilowatts to multiple Megawatts of electrical power. While the relationship between wind speed and wind power production is approximately cubic (i.e., wind power production is proportional to wind speed raised to the third power), real-world wind turbines have minimum and maximum wind speeds (so-called cut-in and cut-out speeds) under which they can produce electricity.

C. Biomass

Biomass refers to renewable organic material that is used to produce energy. The AEPS covers biomass that is burned to generate electricity, and not biomass that is converted to liquid transportation fuels. The cost of electricity generated with biomass fuels depends on the type of biomass being utilized, as well as technological factors. The levelized cost of energy from biomass facilities can range from 6.7 and 15 cents per kWh, making all but the lowest-cost and most-efficient biomass plants economically uncompetitive at current market prices.[5]

D. Landfill Gas

Landfill gas (LFG) is produced at solid waste disposal sites by the decomposition of organic materials. The gas is collected and combusted in a turbine to generate electricity. The economics of installing LFG facilities is driven primarily by the cost of gas collection and the quality of the landfill gas. The levelized cost of existing landfill gas producers is in the range of 5 to 8 cents per kilowatt-hour.[6] However, the cost of erecting a new gas collection system at a landfill can prohibit installing an LFG facility.

E. Waste Coal

Waste coal refers to material that is left over from coal processing operations, or material that is captured during processing but would otherwise be considered refuse. Examples include anthracite culm, bituminous gob, fine coal, lignite waste, coal recovered from a refuse bank or slurry dam, and coal recovered by dredging. Waste coal facilities produce electricity through the combustion of this material. Pennsylvania is the only state whose alternative portfolio standard includes allowances for waste coal. The EPA e-GRID database reports there are eighteen waste coal facilities in the USA, fourteen of which are located in Pennsylvania.[7]

III. The Pennsylvania AEPS standard

The Pennsylvania AEPS requires that an increasing percentage of electricity sales (kWh) in each electric distribution company's (EDC) territory come from designated alternative sources. This percentage began at 4.7% in 2007 and rises to 18 percent by 2020. The alternative resources are divided into two tiers. Tier I resources include photovoltaic energy, solar-thermal energy, wind, low-impact hydro, geothermal, biomass, biologically-derived methane gas, coal-mine methane and fuel cells. In addition, there is a certain amount of the Tier I resource requirement that must be met using photovoltaic technologies. This is referred to as the "photovoltaic carve-out."

Tier II resources include waste coal, distributed generation (DG) systems, demand-side management, large-scale hydro, municipal solid waste, wood pulping and manufacturing byproducts, and integrated gasification combined cycle (IGCC) coal technology. As we will discuss below, Tier II requirements are not difficult for state producers to meet, and therefore

---

[5] Black and Veatch, Renewable Energy Transmission Initiative, report prepared for the California Energy Commission, 2008. Available at http://www.energy.ca.gov/2008publications/RETI-1000-2008-001/RETI-1000-2008-001-D.PDF

[6] Black and Veatch, 2008, *supra*.

[7] The e-GRID database is located online at http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html.

will not likely not impose significant costs on Pennsylvania ratepayers. Therefore, we will not include a discussion of their costs in this report.

The legislated AEPS requirements are as follows:

Compliance Year (CY)[8]	**Tier I (including Solar PV)**	**Tier II**	**Solar PV**
CY 2007	1.50%	4.20%	0.00%
CY 2008	1.50%	4.20%	0.00%
CY 2009	2.00%	4.20%	0.01%
CY 2010	2.50%	4.20%	0.01%
CY 2011	3.00%	6.20%	0.02%
CY 2012	3.50%	6.20%	0.03%
CY 2013	4.00%	6.20%	0.05%
CY 2014	4.50%	6.20%	0.08%
CY 2015	5.00%	6.20%	0.14%
CY 2016	5.50%	8.20%	0.25%
CY 2017	6.00%	8.20%	0.29%
CY 2018	6.50%	8.20%	0.34%
CY 2019	7.00%	8.20%	0.39%
CY 2020	7.50%	8.20%	0.44%
CY 2021	8.00%	10.00%	0.50%

Table 1.1: Pennsylvania Alternative Energy Portfolio Standard as a Percentage of Total Pennsylvania Electricity Consumption. *Source: Pennsylvania Public Utility Commission 2010 Annual Report on Alternative Energy Portfolio Standards,* http://www.puc.state.pa.us/electric/pdf/AEPS/AEPS_Ann_Rpt_2010.pdf

With electricity restructuring in Pennsylvania, most electric utilities were unbundled into separate generation, transmission and distribution companies. Thus, EDCs in Pennsylvania in large part no longer build their own generation assets. EDCs generally meet their AEPS requirements by purchasing the output of renewable generation plants built by independent generating companies. Each Megawatt-hour (MWh) of electricity generated by a qualifying alternative resource generates an "alternative energy credit" (AEC) that can be sold to EDCs or any other interested party. The Pennsylvania AEPS allows in-state requirements to be met either through in-state resources or by "importing" credits from anywhere within the PJM territory. Thus, Pennsylvania EDCs have some flexibility in obtaining credits, since AECs are fungible across state lines. Pennsylvania's policy on credit fungibility stands in contrast to states such as New Jersey, which require some credits to be generated by in-state suppliers.

[8] A compliance year (CY) begins on June 1st of the previous calendar year and ends on May 31st. Thus CY 2012 runs from June 1, 2011 to May 31, 2012.

A. RPS systems in Other States[9]

More than half of U.S. states have adopted renewable portfolio standards or goals. (Goals are generally not legally binding, but do establish renewable energy targets.) These renewable portfolio standards require utilities to meet minimum levels of renewable energy generation and credits by a certain date. Reviewing the renewable plans of all relevant states is beyond the scope of this report. Here we briefly discuss renewable policies of interest in the states that border Pennsylvania: New York, New Jersey, Delaware, Maryland, and Ohio.

Delaware

The Delaware Renewable Portfolio Standard requires a minimum percentage from photovoltaics, sometimes referred to as the Solar Renewable Energy Credit (SREC) requirement. The renewable percentage rises from 2 percent in 2007-8 to 22 percent in 2023-4. The photovoltaic carve out started in 2008-9 and rises to 2.75 percent in 2023-4.

Maryland

Maryland's RPS program mandates 22 percent renewable energy by 2022. For most renewable sources, the generation must be located in the PJM region only; or in a control area that is adjacent to the PJM region, if the electricity is delivered into the PJM region. Photovoltaic energy sources have a somewhat more strict geographic eligibility. Beginning in 2012, photovoltaic energy is only eligible if it is connected with the electric transmission grid serving Maryland. As Maryland is entirely integrated into the PJM market, Maryland's qualifying photovoltaic resources may come from anywhere within the PJM service territory.

---

[9] Information for this section obtained from http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=NJ05R&re=1&ee=1, http://www.njcleanenergy.com/renewable-energy/program-activity-and-background-information/rps-background-info, , http://www.nrel.gov/docs/fy08osti/41409.pdf, http://apps1.eere.energy.gov/states/maps/renewable_portfolio_states.cfm, http://www.dsireusa.org, http://www.azcc.gov/divisions/utilities/electric.asp, http://www.cpuc.ca.gov/PUC/energy/Renewables/index.htm, andhttp://depsc.delaware.gov/electric/delrps.shtml

New Jersey

New Jersey has one of the more aggressive RPS policies in the Mid-Atlantic region. New Jersey requires each energy provider to obtain 22.5 percent of its retail sales in renewable energy credits by the year 2021 (June 2020- May 2021). The mandate sets different requirements for different types of renewable energy resources, termed “classes.” The New Jersey standard also requires that suppliers and providers procure at least 2,518 gigawatt-hours (GWh) from in-state photovoltaic electric generators during energy year 2021, and 5,316 GWh during energy year 2026 and each year thereafter. Note that unlike other state and energy sources, photovoltaic power to meet New Jersey’s mandated requirements must be produced in New Jersey. Class I and II resources are outlined in Table 1.2.

Class I	Class II
Photovoltaic Energy	Small Hydropower Facilities (less than 30MW)
Wind Power	Resource-recovery facilities approved by the Department of Environmental Protection (DEP) and located in New Jersey
Wave or tidal Energy	
Geothermal energy	
Landfill gas	
Anaerobic digestion	
Fuel cell using renewable fuels	
Certain forms of biomass with the approval of the Department of Environmental Protection (DEP)	

Table 1.2 New Jersey Renewable Portfolio Standard Classifications

Photovoltaic energy, while it remains a Class I resource, has special “carve out” requirements, similar to the Pennsylvania requirements for photovoltaics. The general compliance cycle ends in 2021, after which the New Jersey Board of Public Utilities will adopt rules for year 2022 and beyond.

New York

New York’s goal is to reach 30 percent renewable power by 2015. Eligibility is determined by the New York Public Service Commission; the eligibility criteria is generally that the electricity is generated by a resource located in New York, or that it has been contractually delivered into New York and scheduled through one of the energy or ancillary markets run by the New York Independent System Operator.

Ohio

Ohio has a less aggressive target of 12.5 percent renewable energy sales by 2024. At least one-half of the renewable energy resources used to meet the annual targets must come from facilities located in Ohio. The remainder of the resources must come from facilities that can be shown to be deliverable into Ohio. Eligible hydroelectric facilities must be located at a dam on a river, or on any water discharged to a river, that is within or bordering Ohio or within or bordering an adjoining state.

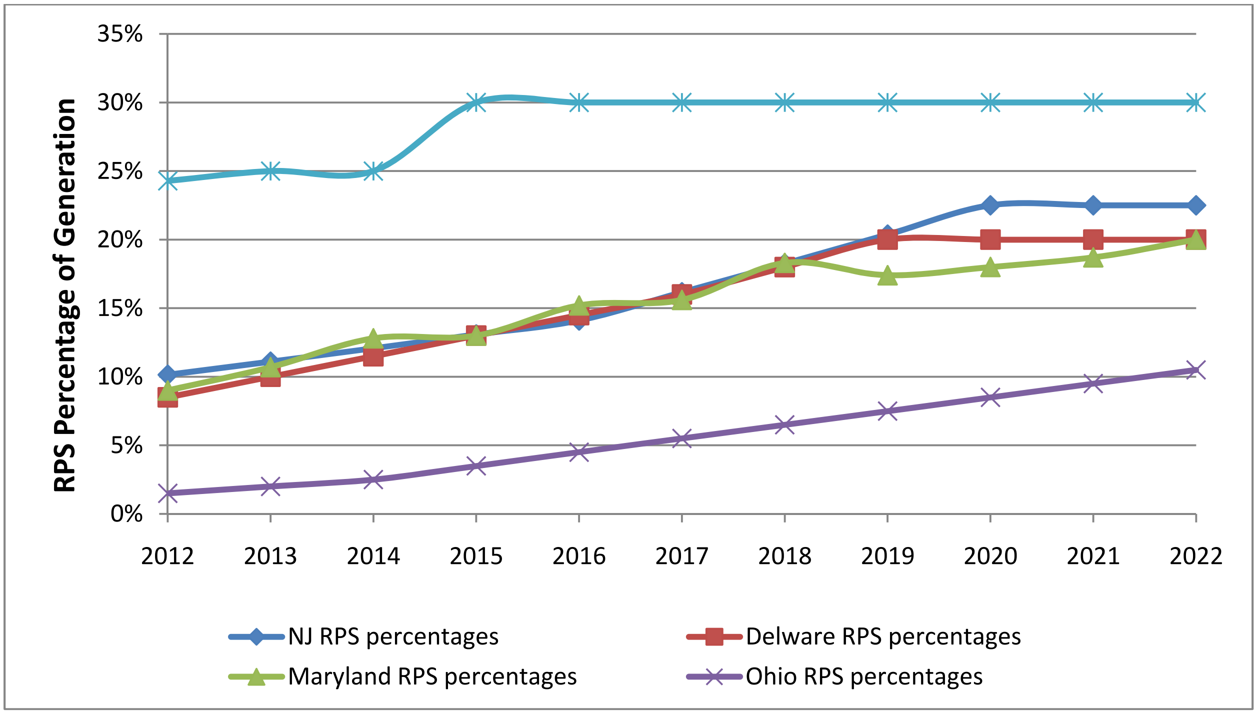


Figure 1.5 – Renewable Portfolio Requirements of Pennsylvania's Neighboring States

Figure 1.5 presents the RPS standards of several states that border Pennsylvania. As the figure indicates, New Jersey has the most aggressive standard, starting at 24 percent of electricity consumption in 2012, and rising to 30 percent by 2015. Ohio, on the other hand, has the least aggressive standard, reaching 10 percent of consumption by 2022.

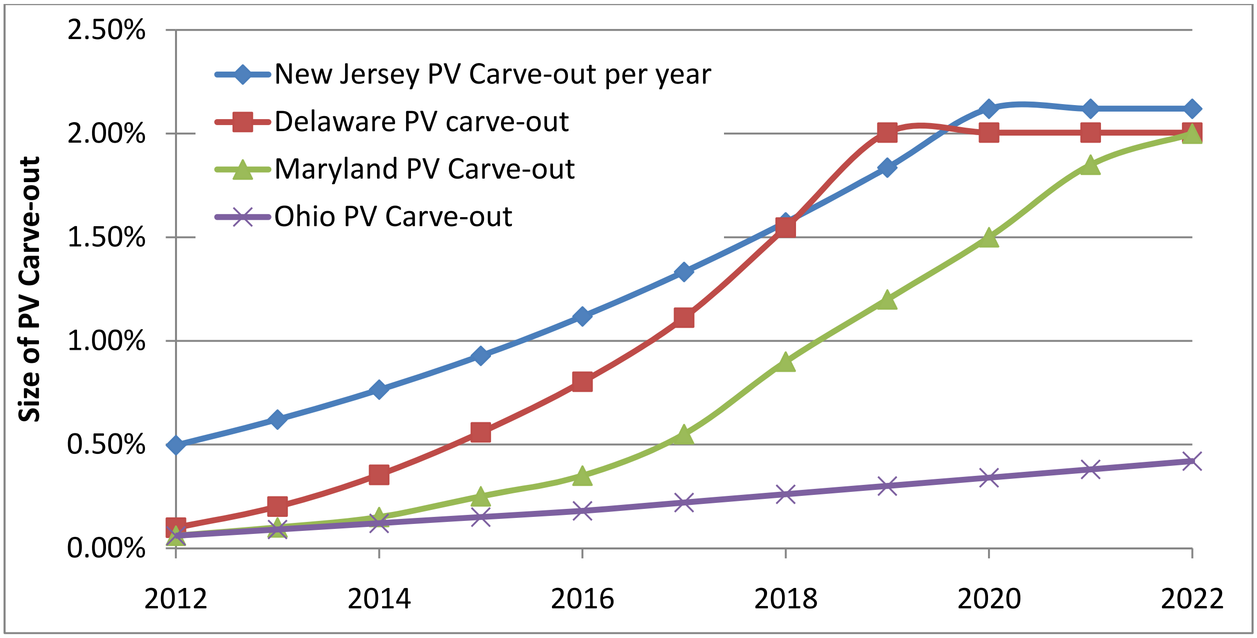


Figure 1.6 – Photovoltaic Carve Out Percentages

Figure 1.6 presents the photovoltaic carve out percentages among Pennsylvania's neighbors. The photovoltaic carve out percentage is important because, as discussed below, the photovoltaic carve can potentially account for a very large part of the costs of portfolio standards, even though they represent a relatively small part of the power requirements. Once again, New Jersey is the most aggressive of Pennsylvania's neighbor states, with its photovoltaic carve out reaching 2.1 percent of demand by 2020, though Delaware's requirements are close. Ohio again is the least aggressive state, with photovoltaic requirements reaching only 0.4 percent of demand.

B. Tracking AECs Within Pennsylvania

AECs generated within Pennsylvania and used by Pennsylvania EDCs to satisfy AEPS standards are tracked by the PJM Generation Attribute Tracking System (GATS) system. The PJM GATS system records eligible credits for the PJM region and shows where the credits were retired. The CY 2010 credits generated in Pennsylvania by fuel source are shown below in Table 1.3.

TIER I			TIER II		
Fuel	**Quantity of AECs**	**(%)**	**Fuel**	**Quantity of AECs**	**(%)**
Black Liquor (BLQ)	408,774	12.58	Blast Furnace Gas (BFG)	302,657	1.74
Landfill gas (LFG)	966,131	29.73	Energy Efficiency (EE)	250	0.00
Biomass- Other biomass gases (OBG)	4,149	0.13	Pumped Storage (HPS)	2,452,684	14.06
Photovoltaic (SUN)	9,498	0.29	Municipal Solid waste (MSW)	1,632,023	9.36
Hydroelectric (WAT)	128,479	3.95	Gas- Natural Gas (NG)	33,168	0.19
Wood- Wood waste Liquids (WDL)	51,064	1.57	Gas – Other (OG)	127,407	0.73
Wood- Wood waste Solids (WDS)	127,250	3.92	Other (OTH)	406	0.00
Wind (WND)	1,553,822	47.82	Hydroelectric (WAT)	2,232,224	12.80
Total	3,249,167	100	Coal –waste coal (WC)	10,603,404	60.80
			Wood – wood waste solids (WDS)	56,447	0.32
			Total	17,440,670	100

Table 1.3: Pennsylvania generated AECs by fuel (CY 2010). *Source: PJM GATS*, https://gats.pjm-eis.com/myModule/rpt/myrpt.asp?r=242&TabName=In-State

Table 1.3 shows that about 48 percent of Tier I resources generated in Pennsylvania come from wind. Other important contributors to Tier I are landfill gas (30 percent) and black liquor (13 percent). Of the Tier I resources, wind and photovoltaic represent the greatest potential for building additional facilities within Pennsylvania borders.

A review of proposed new generation facilities in Pennsylvania shows many wind and photovoltaic projects, but only limited number of other Tier I energy sources.[10] Tier I projects other than wind or photovoltaics represent only 8.25 percent of the total Tier I projects in the PJM queue for 2011, and 9.73 percent for 2012. For 2013 and 2014 this numbers fall to 0.27 and 0.51 percent. (We note that it is quite common for generation plants in the queue to never come into service.) Given these figures, our analysis below will assume that the non wind/photovoltaic Tier I supplies will increase by 4.7 percent of the increase in the total Tier I requirements (as 4.7 percent is the average fraction for 2011-2015 in the PJM generation queue).

AECs generated in Pennsylvania are retired for compliance in a number of states. Table 1.4 below shows the distribution of Pennsylvania AECs retired for CY 2010 and those that were retired to meet RPS compliance in other states in the PJM region.

[10] This data was obtained from http://pjm.com/planning/generation-interconnection/generation-queue-active.aspx

Tier	Tier 1	%	Photovoltaic	%	Tier 2	%
Available (a)	2,002,326	61.81	7,099	74.74	16,266,015	93.26
Used for 2010 Compliance (b)	1,079,193	33.31	2,390	25.16	1,147,952	6.58
Sold (c)	70,701	2.18	0	0.00	12,500	0.07
Other (d)	42,123	1.30	9	0.09	14,203	0.08
Retired- Env (e)	10,265	0.32	0	0.00	0	0.00
Retired – Export (f)	35,061	1.08	0	0.00	0	0.00
Total	3,239,669	100	9,498	100	17,440,670	100

Definition of terms:

(a) Available- This refers to generated credits that were left unsold/banked during the compliance year 2010.
(b) Used for 2010 Compliance- This refers to credits used by the Account Holder for compliance with a PJM-state Renewable Portfolio Standard.
(c) Sold – This refers to credits sold as a part of a retail Certificate-only product to an end-use customer in PJM that does not have a GATS account. For example: Sold to residential or commercial customers making voluntary purchases. Sold to event organizers so that events can offset their electricity or make environmental claims.
(d) Other – This refers to credits posted for sales but awaiting confirmation as at year end.
(e) Retired- Env- This refers to credits used by the Account Holder to make environmental claims or to take out of circulation for environmental benefits reasons.
(f) Retired – Export- This refers to generated credits exported (sold) off-system to a third party in a region that might have a compatible tracking system.

See Generation Attribute Tracking System (GATS) Operating Rules, Page 54, http://www.pjm.com/~/media/pjm-eis/documents/gats-operating-rules.ashx

Table 1.4: Pennsylvania Generated Credits at the end of CY 2010

The above shows that there were more credits are left unsold than credits retired in 2010. For Tier I requirements, it may be that firms are storing credits to use for later years. Observe, however, that the Tier II credits generated far exceed current and future AEPS Tier II requirements. Thus, it is unlikely that significant new generation investment will occur to produce additional Tier II credits under AEPS. Given this, we will focus on the costs associated with meeting Tier I requirements for the remainder of this report.

State	Tier 1	Photovoltaic	Tier II	Net exports
DC	0	530	12,270	12,800
DE	56,639	-1,607	0	55,032
IL	-109,525	-988	0	-110,513
IN	-500	0	0	-500
MD	98,981	7	128,713	227,701
MI	-15,797	0	0	-15,797
NJ	813,600	-51	411,953	1,225,502
OH	-76,922	933	-24,578	-100,567
VA	-8	0	33,397	33,389
WV	-2,965	0	-7	-2,972
Net exports	763,503	-1,176	561,748	1,324,075

Table 1.5: Pennsylvania Net Exports of Credits by State, 2010

As discussed above, many states have made their portfolio standard credits fungible across states served by the PJM regional system operator. Table 1.5 presents the net exports for Pennsylvania. As can be seen, Pennsylvania is a large net exporter of Tier I credits, although it is a minor importer of photovoltaic credits.

C. Prices in Alternative Energy Credit Markets.

The GATS system also presents the trading prices of alternative energy credits used in the PJM region. Prices for photovoltaic credits tend to be higher than credit prices for other alternative generation technologies. Photovoltaic credits in Pennsylvania credits sold in the $300/MWh range in 2010 and have sold in the $200/MWh range in 2011. This is in contrast to an average wholesale price of electricity of $45.51/MWh in the PJM market of during the first half of 2011.[11]

Maryland and New Jersey photovoltaic credit prices tend to be higher than those in Pennsylvania. In Maryland, photovoltaic credits at the beginning of 2011 sold in the range of $350/MWh. In New Jersey, which has a more aggressive photovoltaic carve-out, photovoltaic credits sold at the beginning of 2011 in the $650/MWh range. Prices for these permits have declined, however, in recent months.

---

[11] Pennsylvania Public Utility Commission, http://www.puc.state.pa.us/electric/electric_alt_energy.aspx; PJM State of the Market Report, January-June 2011, http://www.monitoringanalytics.com/reports/PJM_State_of_the_Market/2011.shtml. We note that credit market prices may necessarily be highly volatile due to a number of factors: the demand for renewable power is fixed by state mandate; marginal costs of production are essentially zero; output is variable and cannot be controlled by producers; and photovoltaic module prices are expected to decline over time.

Differences across states in photovoltaic credit prices arise from the fact that photovoltaic credits are not always entirely fungible across states. If, for example, Pennsylvania photovoltaic credits could be used in New Jersey, the price of photovoltaic credits in New Jersey could not rise far above the Pennsylvania price. In these examples, however, neither Maryland nor New Jersey allow for the import of photovoltaic credits. Because the Maryland and New Jersey photovoltaic requirements are more aggressive than those of Pennsylvania, and because no imports are allowed, the price of photovoltaic credits in those states are above those in Pennsylvania.

Credits for wind energy sell for far less than those of photovoltaic energy. In 2010 wind energy credits in Pennsylvania sold for an average of $4.77,[12] far below the cost of photovoltaic credits. This implies that meeting Pennsylvania's Tier I AEPS requirements with wind power will be far less, per MWh generated, than with photovoltaic power.

The natural conclusion from the AEC price data is that wind energy is currently available at a small premium above the market price because the costs of producing it are not far above the market price of power. Photovoltaic power costs, however, remain quite high relative to other renewable energy technologies. AEC price data suggest that that the "all-in" costs of photovoltaic power (module cost and photovoltaic AEC cost) are far above current market prices for electricity. This implies that the photovoltaic carve-out in Pennsylvania likely increases the cost of compliance with AEPS, compared to substituting wind energy or other Tier I technologies.

As photovoltaic and wind energy appear to be the dominant technologies that will be used to satisfy AEPS over the next several years, we turn to an analysis of the costs of expanding photovoltaic and wind energy in Pennsylvania. Our primary goal is to estimate a "supply curve" for wind and photovoltaic energy, which describes changes in costs as additional resources are built-out. We emphasize here that our initial analysis assumes that technology for wind and photovoltaic energy remains constant, in terms of cost and performance.

The scope of our project does not allow us to explore supply and demand curves for renewable technologies across the PJM region. Thus, in our analysis we will assume that Pennsylvania is self-sufficient in generating AECs. If, however, Pennsylvania continues to export such credits, it will imply more production of credits in Pennsylvania than we estimate below. This, in turn, will imply a move upward on the supply curve for credits and therefore higher costs for Pennsylvania ratepayers.

[12] Pennsylvania Public Utility Commission, http://www.puc.state.pa.us/electric/electric_alt_energy.aspx.

IV. The Choice of Interest Rate

Investment in a renewable generation facility involves spending money in the present in order to gain returns in the future. Future values, on a dollar per dollar basis, however, are not equal to current values. Thus, future values must be discounted by the relevant discount or interest rate. As will become evident in Sections V and VI, the estimated cost of Pennsylvania's AEPS is highly sensitive to the choice of interest rates, so we discuss our choice of rates in this section.

Investment funds for power generation facilities generally come from two sources: loans to the investor, and investment equity. The composite interest rate is known as the weighted average cost of capital (WAC).[13] Assuming that investments are financed entirely through debt and equity, the WAC for any investment is determined by the formula:

> WAC = [(Percent Capital from Debt)(Interest rate on Debt) + (Percent Capital from Equity)(Interest rate on Equity)]/100.

Thus, we need to find values for the proportions involved in debt/equity financing, as well as representative interest rates. We must further adjust the interest rate for inflation, utilizing a "real" interest rate. Most interest rates are quoted in terms of the "nominal" interest rate, where the nominal rate minus the rate of inflation is equal to the real rate. A good approximation for the current rate of inflation is 2 percent. [14]

M. Ragheb reports that the average return on debt on renewable generation investments is the prime rate of interest plus 2 percent.[15] The prime interest rate as of this writing was 3.25 percent.[16] Thus, the real interest rate of debt used here will equal 3.25 + 2 – 2 = 3.25 percent. Ragheb also reports that the rate of return on equity for renewable investment generation ranges from 15 to 18 percent. Thus, the real rate of return on equity will be in the range [18-2; 15-2], or from 13 to 16 percent. Because loan payments are paid before capital payouts (that is, debt is senior to capital) the interest rate on loads is generally less than that of equity.

In general, the debt share of financing on generation projects is 50 percent.[17] Ragheb suggests, however, that for renewable generation projects this number is likely to be higher. The reason for the higher debt share is that loans for renewable generation projects are often

[13] See, for example, Ross, Westerfield, Jaffe, and Jordan, *Corporate Finance: Core Principle and Applications*, 2008.

[14] http://www.fintrend.com/inflation/inflation_rate/CurrentInflation.asp,

[15] M. Ragheb, Wind Project Development and Financing, 2009. Available at https://netfiles.uiuc.edu/mragheb/www/_NPRE%20475%20 Wind%20Power%20Systems/ Wind%20Project%20Development%20and%20Financing.pdf

[16] http://www.bankrate.com/rates/interest-rates/prime-rate.aspx?ec_id=m1027769. Note that in historical terms, current interest rates are very low.

[17] National Energy Technology Laboratory, "Cost Estimation Methodology for NETL Assessments of Power Plant Performance," 2011.

guaranteed by the Federal government. Here we will assume that the debt percentage of capital is 70 percent, implying the equity percentage is 30 percent.

We are now in position to calculate the WAC for the high and low levels of return on equity. For the high level of return on equity the WAC equals:

$$WAC_{HIGH} = ((70\times3.25)+(30\times16))/100 = 7.075 \text{ percent.}$$

Similarly, the WAC for the low level of return on equity equals:

$$WAC_{LOW} = ((70\times3.25)+(30\times13))/100 = 6.175 \text{ percent.}$$

In the analysis that follows, we will assume a high interest rate of 7.5 percent and a low interest rate of 6 percent. While this appears to be a narrow range, a 1.5 percent difference in interest rate can translate to large differences in AEPS implementation costs.

V. The Costs of Photovoltaic Power

A. Photovoltaic Potential in Pennsylvania

In order to estimate the costs of solar photovoltaic energy requirements in Pennsylvania, it is important to have an idea of the quality of photovoltaic energy and the level of variability across the state. Actual data on photovoltaic electricity generation in Pennsylvania is limited, since most of the photovoltaic power in the state is generated from small-scale rooftop installations. Photovoltaic resource maps of the U.S., such as that shown in Figure 5.1 suggest a small increase in photovoltaic resource capability moving from Erie in the Northwest to Philadelphia in the Southeast. If photovoltaic energy is to be generated in Pennsylvania, it would make sense, all other things being equal, for it to be produced in the most advantageous location.

Since there appears to be little difference in the efficiency of solar photovoltaic generators across the state, we will assume that the capacity factor of solar photovoltaic resources in Pennsylvania does not decline as the quantity of photovoltaic power generated increases. In economic terms, this implies a “flat” supply curve. In our analysis of the costs of photovoltaic energy, we will also assume that the photovoltaic power sites are located in eastern Pennsylvania, where wholesale electricity prices are generally higher than in western Pennsylvania. Note that this assumption will serve to reduce the estimate of the costs of Pennsylvania’s solar photovoltaic carve-out.

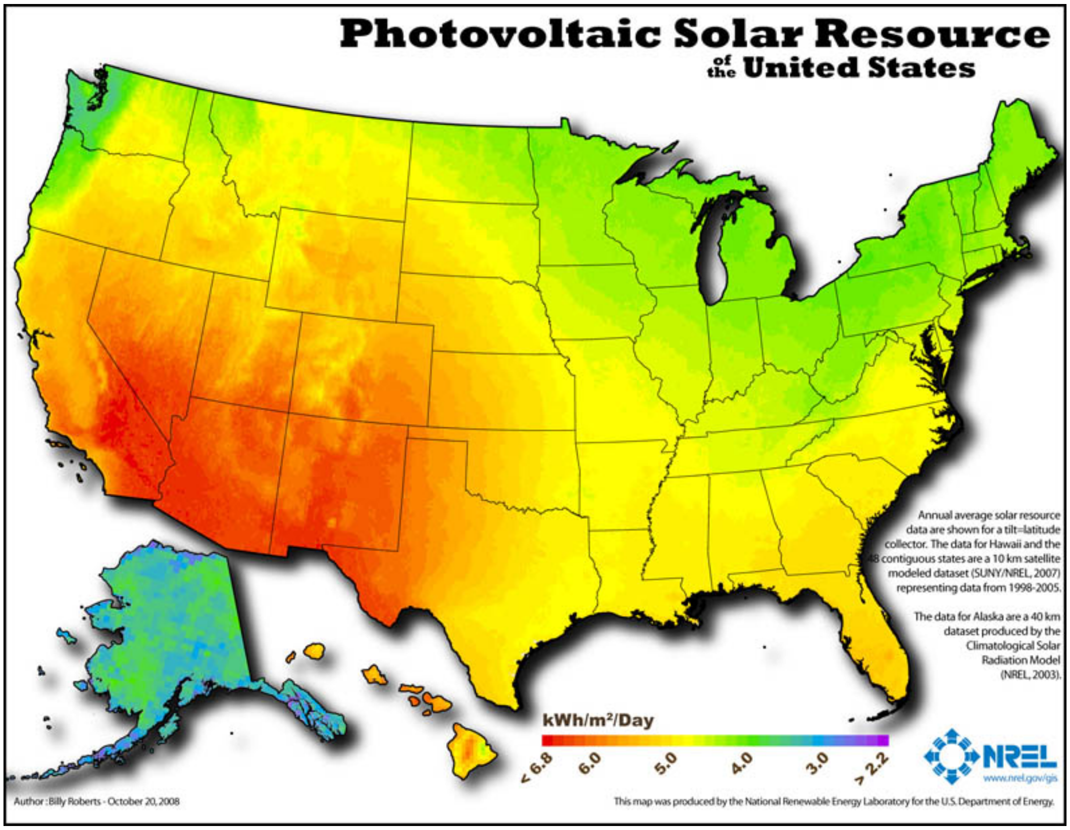


Figure 5.1: Photovoltaic Resource of the United States (Source: NREL)

B. The Cost of Solar Photovoltaic Energy in Pennsylvania

We are now in a position to calculate the cost of energy for photovoltaic power in Pennsylvania. In a competitive market, firms can be expected to enter until the long run average cost for their product equals the price they obtain in the market. The average cost of energy over the lifetime of a new power plant is often referred to as the Levelized Cost of Energy (LCOE). The LCOE represents the break-even price for a new power plant investment, or the average price the owner would need to receive over the life of the plant to recover all relevant costs.

As stated above, the capacity factor for photovoltaic power in Pennsylvania is assumed to be 19.08 percent.[18] Given that there are 8,760 hours per year, a photovoltaic installation with one kilowatt of capacity would produce 0.1908 × 1 kW × 8760 hours/year = 1,670.5 kWh per year.

---

[18] This figure is derived using photovoltaic simulations in the TRNSYS modeling environment. See A. Klein et al. (2006) TRNSYS, A Transient System Simulation Program, Users Manual, Version 16" Solar Energy Laboratory, University of Wisconsin. We thank our colleague Jeffrey Brownson for assistance with these simulations. Also see M. Bayrakci (2010) "Temperature Dependent Power modeling of Photovoltaics". MS Thesis, Department of Energy and Mineral Engineering, The Pennsylvania State University, http://etda.libraries.psu.edu/theses/ approved/PSUonlyIndex/ ETD-6886/ index.html, and L. Witmer (2010) Quantification of the Passive Cooling of Photovoltaics Using a Green Roof," MS Thesis, Department of Energy and

Published estimates of the useful life of photovoltaic panels in Pennsylvania range from 20 to 30 years.[19] We therefore assume a lifespan of 25 years., and that the time-to-build for a photovoltaic installation in Pennsylvania is one year. The capital cost of a solar photovoltaic panel is assumed to be $4,000 per kW of generation capacity in 2010. While fuel from the sun is free at the margin, we assume maintenance costs of $50 per kW of capacity per year.[20] For the purposes of this analysis, we will initially assume a 6 percent real interest rate. We note that the higher the interest rate, the higher the LCOE for photovoltaic power, the higher the price consumers must pay for photovoltaic power, and the higher the cost of the photovoltaic carve-out in Pennsylvania's AEPS.

A 25-year stream of annual $50/kW-year payments, discounted at 6 percent annually, with a one-year delay, has a net present value of $639 per kW. The total present discounted cost of our hypothetical photovoltaic panel is thus $4,639 per kW. This implies that if the photovoltaic panel produces 21,366 kWh over the 25-year period (1,671 kWh per year, discounted at 6 percent annually) then the energy price *P* that solves the equation 21,366 × *P* = $4,6 is $217.12 per MWh, or about 21.7 cents per kilowatt-hour.

The prevailing LCOE for a given photovoltaic project in Pennsylvania will vary depending on the relevant real discount rate. We performed a similar analysis using a 7.5 percent interest rate and found using that interest rate the LCOE of photovoltaic power would be $244.61/MWh. These levelized costs are presented in Table 5.2 below.

Interest Rate	**LCOE**
6%	$217.12
7.5%	$244.61

Table 5.2: 2010 Levelized Cost of Photovoltaic Energy ($/MWh), Interest Rates of 6 and 7.5 percent

Capital costs are a significant determinant of the LCOE for electricity produced using PV technology. The cost of producing PV power has been declining at a rate of approximately 15 to

Mineral Engineering, The Pennsylvania State University, http:// etda.libraries.psu.edu/ theses/approved/ WorldWideFiles / ETD-5720/ LucasWitmer-MSThesis.pdf.

[19] http://solar-module-panels.com/pv/module-life-span/ assumes a 20-year life, while analyses based on 25-year life and 30-year life are shown in B. van der Zwaan and A. Rabl, "Prospects for PV: A Learning Curve Analysis," *Solar Energy* 74 (2003), pp. 19-31.

[20] This figure is taken from http://www.pennfuture.org/UserFiles/File/Legislation/HB80SB92_Report201001.pdf

20 percent per year for at least two decades.[21] Thus, it is reasonable to expect that PV costs will decline going forward from 2010. The amount of that decline, however, is difficult to pinpoint.

While the cost of PV modules has declined rapidly, there is some uncertainty as to whether these cost declines will continue at the same rate over the next decade. Industry expectations are that PV module costs will become economically competitive with the capital costs of conventional fossil plants within a decade, driven by a mix of technological advances and other improvements in production efficiency.[22] Recent analyses of PV cost declines suggest two driving factors.[23] The first is an increase in the scale of PV production (driven by photovoltaic mandates such as Pennsylvania's), during which smaller firms have been replaced by larger firms with lower production costs. It is unclear whether additional economies of scale can be exploited. The second element is a reduction in cost of various inputs into PV power, especially silicon.[24] Again, it difficult to know if this will continue.

Year	**Low Innovation Path**	**High Innovation Path**
2010	$217.30	$217.30
2011	$212.95	$195.57
2012	$208.69	$176.01
2013	$204.52	$158.41
2014	$200.43	$142.57
2015	$196.42	$128.31
2016	$192.49	$115.48
2017	$188.64	$103.93
2018	$184.87	$93.54
2019	$181.17	$84.19
2020	$177.55	$75.77
2021	$174.00	$68.19

Table 5.3: Production Cost of Solar Power Over Time, Assuming Low and High Innovation Paths, 6% Interest Rate

Given the uncertainty in the future cost of PV technologies, we will posit two scenarios for assessing the costs of Pennsylvania's PV carve-out through 2021. The first we will refer to as a "low innovation" path, with PV costs declining 2 percent per year. The second we will refer to

[21] G. F. Nemet, "Beyond the Learning Curve: Factors Influencing Cost Reduction in Photovoltaics," *Energy Policy* 34:17 (2006), pp. 3218-3232.

[22] "Solar Energy: The Quest for Cheap: *Business Week*, available at http://www.businessweek.com/technology/solar-energy-the-quest-for-cheap-10132011.html.

[23] Nemet, *supra*, and "A Painful Eclipse," *The Economist* 15 October 2011, http://www.economist.com/node/21532279.

[24] Nemet, *supra*.

as a "high innovation path" with PV costs declining 10 percent per year. While the two assumptions will produce dramatically different results, we do not believe it would be appropriate to narrow the innovation assumptions any further.

Table 5.3 lays out the path of PV costs, using the high and low innovation paths, and an interest rate of 6 percent per year. The cost implications of the low innovation path as compared to the high innovation path are substantial. Assuming the high innovation path, the cost of PV power declines to a little more than $68/MWh in 2021. Assuming a low innovation implies a PV cost of over $174/MWh, almost triple the high innovation path amount.[25]

C. Photovoltaic Resources Opportunity Price

The cost of photovoltaic power mandates are a relative cost. The relevant question to ask is not simply the cost of the photovoltaic set-aside, but rather the market price of the power that photovoltaic energy replaces. We will refer to this as the "opportunity price" of photovoltaic energy (we will use a similar concept for assessing the costs of wind energy in Section VI). The relative price of photovoltaic energy in Pennsylvania certainly appears large, since we estimate a LCOE for photovoltaics that is roughly one order of magnitude larger than the average annual wholesale energy price in PJM.

We use a four-step methodology to estimate the opportunity price of photovoltaic energy. First we obtain nodal prices at a power node in eastern Pennsylvania. As noted above, power prices are higher in eastern Pennsylvania than western Pennsylvania. The nodal price represents the spot price paid to all generators (coal, natural gas, wind, photovoltaic, etc.) at a particular location in the electricity grid at a particular time.[26] We obtain these prices on an hourly basis. Second, we obtain data on photovoltaic power output by hour for each month. The average opportunity price of photovoltaic power in a given month is determined by calculating the load-weighted average nodal electricity price for that month. Finally, an annual average opportunity price of photovoltaic energy is calculated by taking the weighted average of the monthly opportunity prices.

In order to calculate the opportunity price of photovoltaic energy in Pennsylvania, the hourly price of photovoltaic energy is compared to the levelized cost of photovoltaic energy. The hourly price of Schuylkill Haven node in eastern Pennsylvania is used.[27] Nodal price averages vary widely across months and times of day. Thus, for example, the highest monthly average

[25] Indeed, a more rapid innovation path (above 10%) would imply that PV power would be close to competitive with conventional generation resources without the AEPS standards by 2021.

[26] For example, if a generator produces 50 MWh of power during a time period where its nodal price of electricity is $40/MWh, and sells that power into the spot market, that producer will receive 50×40=$2000.

[27] Data was gathered from PJM, http://www.pjm.com/markets-and-operations/energy/real-time/monthlylmp.aspx. Schuylkill Haven is used as an example of a specific nodal price prevailing in Eastern Pennsylvania, where nodal prices are generally higher than in the Western half of the state. Prices are generally highest in the Philadelphia region, but an urban setting would likely limit severely the generation of utility-scale solar photovoltaic energy.

nodal price is $179.90/MWh, between 4 pm and 5 pm in August. The lowest monthly average nodal prices are $22.40/MWh, between 3 am and 4 am in both October and December.

The average photovoltaic output, in percentage terms, for each hour of each month is multiplied by the corresponding average hourly price in that month. Summing over all hours generates a monthly average photovoltaic opportunity price, as shown in Table 5.4 for January 2010. Note that only 10 hours are used for January, as in January the other hours are (almost entirely) dark. The product of the second and third columns is presented in the fourth column, which is the hourly contribution to the photovoltaic opportunity price for that month.

At this point, we gain photovoltaic output by month, and calculate the percentage monthly contribution to the photovoltaic energy total. We multiply the monthly photovoltaic percentage output by the monthly photovoltaic average opportunity price. We then add up the twelve components to determine the average photovoltaic opportunity price across the year.

Hour	**January Output %**	**January Average Nodal Price ($/MWh)**	**Contribution to January Average Price ($/MWh)**
8	1.53%	$27.20	$0.42
9	6.13%	$27.80	$1.71
10	11.35%	$29.80	$3.38
11	14.11%	$32.20	$4.54
12	14.42%	$33.70	$4.86
13	16.26%	$36.70	$5.97
14	14.72%	$33.70	$4.96
15	11.35%	$31.30	$3.55
16	7.36%	$31.60	$2.33
17	2.76%	$49.70	$1.37
Total	100.00%		$33.09

Table 5.4: Calculating the Average Photovoltaic Nodal Price for January 2010, Schuykill Haven Node

The monthly average nodal prices are shown in Table 5.5. A single annual photovoltaic-weighted nodal price is calculated by taking the average of these monthly nodal prices, using the relative amount of solar photovoltaic production in each month as weights. (These percentages are shown in the second column of Table 5.4.) As shown in Table 5.4, we estimate that the average annual photovoltaic opportunity price is $53.96/MWh.

Month	**% of output**	**Average Price ($/MWh)**	**Contribution to Yearly Average Price ($/MWh)**
January	6.36%	$33.09	$2.11
February	7.93%	$36.90	$2.93
March	8.90%	$36.86	$3.28
April	9.37%	$36.21	$3.39
May	9.49%	$82.48	$7.83
June	9.74%	$64.66	$6.30
July	9.68%	$46.22	$4.48
August	9.88%	$61.41	$6.07
September	8.86%	$108.64	$9.63
October	8.30%	$38.32	$3.18
November	6.35%	$37.04	$2.35
December	5.13%	$47.28	$2.43
Total	100.00%		$53.96

Table 5.5: Calculated Annual Photovoltaic Opportunity Price

Photovoltaic output is naturally the highest around noon, and zero at night. Photovoltaic output, however is not quite coincident with peak electricity prices, which tend to occur between 4 and 6 in the afternoon. Figure 5.2 below outlines the difference between the photovoltaic peak (at noon) and the peak electricity price (at 5pm) for August at Schuykill Haven.

As expected, photovoltaic output peaks at noon standard time. In August, however, Pennsylvania is on Daylight Savings Time, implying that PV output peaks at 1:00 PM local time. In August, the price of power at Schuylkill Haven had two peaks, one at noon and one later in the afternoon. Because photovoltaic power is not generated at night, when power prices are the lowest, this raises the opportunity price of photovoltaic power. Photovoltaic power is relatively low, however, during afternoon peak prices. This lowers the opportunity price of photovoltaic power.

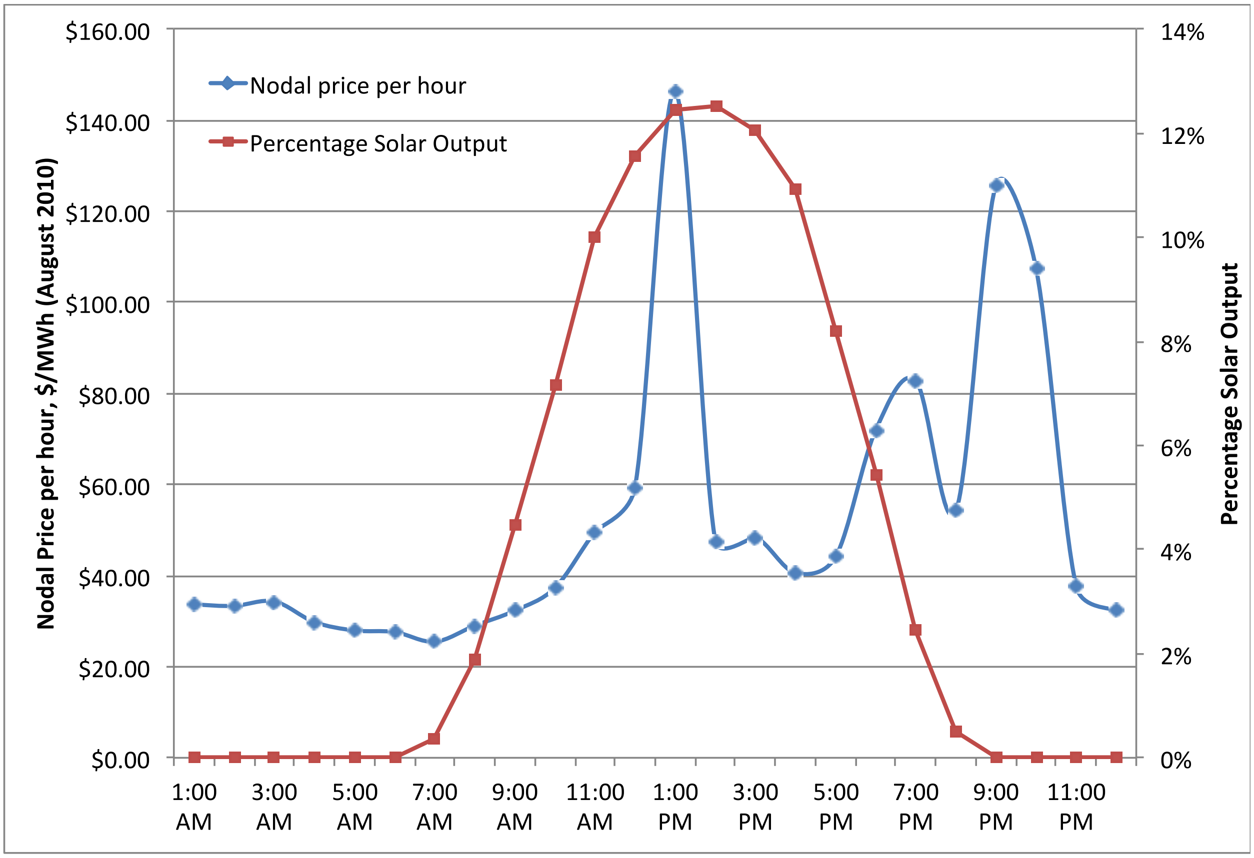


Figure 5.2: Nodal price /Percentage photovoltaic output per hour Schuylkill Haven Node, August 2010

The unweighted average price of power across the Schuylkill Haven node is $49.99/MWh. The photovoltaic opportunity price of $53.96/MWh is slightly above the unweighted average, indicating a small positive correlation between photovoltaic output and peak price.

We are now in a position to calculate the cost of photovoltaic energy to Pennsylvania consumer per MWh. This is simply the LCOE of solar photovoltaic power minus the photovoltaic power opportunity price of $53.96/MWh. Given this, the opportunity prices of photovoltaic energy in Pennsylvania over time are shown below in Table 5.6.

	Low Innovation Path		High Innovation Path	
Year	**6% interest rate**	**7.5% interest rate**	**6% interest rate**	**7.5% interest rate**
2012	$154.73	$180.95	$122.05	$144.16
2013	$150.56	$176.25	$104.45	$124.35
2014	$146.47	$171.65	$88.61	$106.52
2015	$142.46	$167.14	$74.35	$90.47
2016	$138.53	$162.72	$61.52	$76.03
2017	$134.68	$158.38	$49.97	$63.03
2018	$130.91	$154.13	$39.58	$51.33
2019	$127.21	$149.97	$30.22	$40.80
2020	$123.59	$145.89	$21.81	$31.32
2021	$120.04	$141.90	$14.23	$22.80

Table 5.6: Cost to consumers of photovoltaic mandate, per MWh of photovoltaic production, 2012 to 2021

As Table 5.6 indicates, the cost of solar power per MWh varies widely based on the assumption of interest rate and the rate of innovation. Thus, with an interest rate of 7.5 percent and a low innovation path, the cost of the PV carve out in 2021 would be almost $142/MWh. With the high innovation path and interest rate of 6 percent, the cost in 2021 would be slightly over $14/MWh.

VI. The Cost of Wind Power

A. The Wind Resource Potential in Pennsylvania

Unlike the case with photovoltaic energy, wind energy resources are not uniform throughout the state. Pennsylvania's varied geography of ridgetops and valleys makes wind energy potential highly site-specific. While most areas in Pennsylvania could likely produce at least some wind energy over the course of a year, there are fewer locations in Pennsylvania where wind energy investments would be worthwhile. Figure 6.1 shows estimated average annual wind speeds in Pennsylvania at a hub height of 80 meters (approximately the hub height of modern utility-scale wind turbines). The most advantageous on-shore wind resources in the state are located along the ridgetops of the Alleghenies, which stretch from Southwestern to Central Pennsylvania; the mountaintops of Northeastern Pennsylvania; and in proximity to Lake Erie in Northwestern Pennsylvania. Figure 6.1 does not include any resource assessments for offshore wind in Pennsylvania's Lake Erie waters. While offshore wind resources are generally of higher quality than onshore wind resources (i.e., winds have higher average speeds and are more sustained), offshore wind energy investments are more costly to construct.

The available wind resources in Pennsylvania are further limited by geography and land ownership; utility scale wind, for example, is unlikely to be built in highly developed areas or environmentally sensitive areas such as state parks or state and national forests. Figure 6.2 provides an estimate of wind resource quantity (MW of capacity) at various capacity factors, accounting for Pennsylvania's varied topography and possible site-specific restrictions on wind energy development.

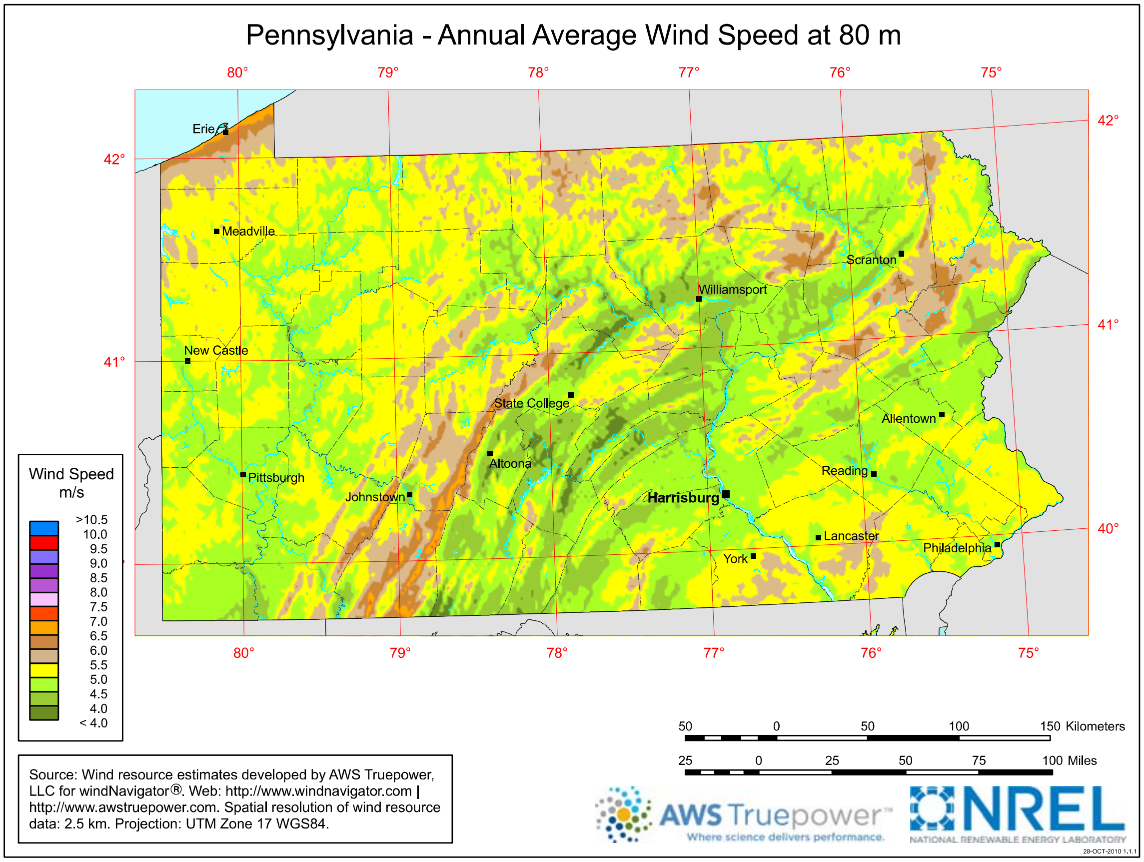
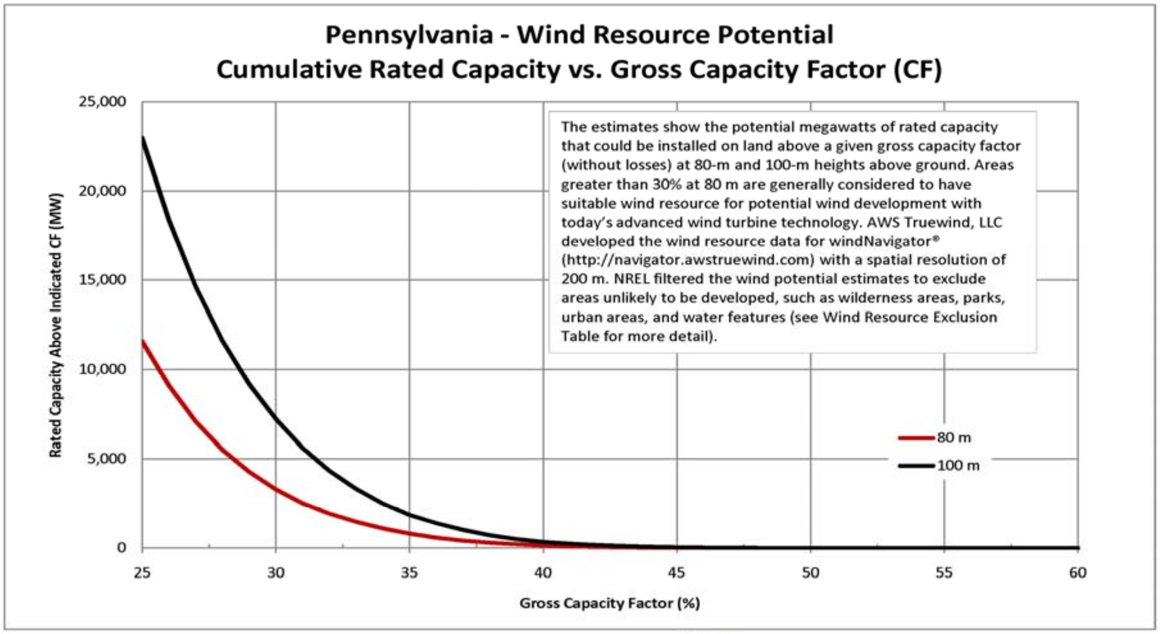


Figure 6.1: Average annual wind speeds in Pennsylvania. *Source: NREL*



NREL NATIONAL RENEWABLE ENERGY LABORATORY

AWS Truepower™ Where science delivers performance.

Figure 6.2: Pennsylvania Wind Resource Potential Curve. *Source: NREL*

Given these properties of wind energy potential in Pennsylvania, the levelized cost of additional wind energy at the margin will depend on the capacity factor of the marginal new wind resource, as well as the project costs. Our analysis in this section assumes that the wind resources with highest capacity factor (i.e., lowest levelized cost of energy) would be built-out first, followed by resources with incrementally lower capacity factors. This assumption reduces the estimated cost of the AEPS. In reality, wind energy siting decisions depend on a large number of factors including local spot electricity prices in the PJM market; land availability; access to the PJM grid; and siting or permitting.

B. Estimating the LCOE for Wind Power in Pennsylvania.

We base our LCOE calculations on cost figures from the U.S. Energy Information Administration.[28] According to the report, the capital cost for wind power is $2,438/kW. Fixed operating and maintenance costs are $28.07/kW-year, while the variable costs are $0.01/MWh. The life span of a wind turbine is assumed to be 25 years. We calculate LCOEs for discount rates of 6 and 7.5 percent per year. We assume a delay time for building of one year. The Federal Production tax credit for wind projects of 2.1 cents per kWh is also used.

[28] U.S. Energy Information Administration, "Capital Cost Estimates for Power Generation Plants," 2010. *www.eia.gov/oiaf/beck_plantcosts/pdf/updatedplantcosts.pdf*

The LCOE for wind power is calculated in a similar manner as that for photovoltaic energy. The revenues consist of the net present value of a 25-year stream of power as a function of the capacity factor times the LCOE, delayed one year. Costs are computed as the upfront capital costs plus the discounted stream of maintenance costs and (here) variable costs. We calculate the wind energy LCOE for different capacity factors, as well as different interest rates. The results, calculated for interest rates of both 6 and 7.5 percent, are in the table below.

Capacity factor	**LCOE ($/MWh) @ 6% discount rate**	**LCOE ($/MWh) @ 7.5% discount rate**
0.25	65.98	77.28
0.26	63.02	73.88
0.27	60.27	70.74
0.28	57.73	67.82
0.29	55.36	65.10
0.3	53.15	62.56
0.31	51.08	60.19
0.32	49.14	57.97
0.33	47.32	55.88
0.34	45.60	53.91
0.35	43.98	52.05
0.36	42.46	50.30
0.37	41.01	48.65
0.38	39.64	47.08
0.39	38.34	45.59
0.4	37.11	44.17

Table 6.1: LCOE of wind energy at different discount rates and capacity factors

Thus, the amount of wind power available at different capacity factors becomes crucial to creating a wind energy supply curve. Figure 6.2 showed such a curve; some specific numbers obtained from NREL are in Table 6.2. Note that the figures in the right-hand column of Table 6.2 are cumulative.

Capacity factor	Rated Cumulative Capacity (MW)
0.25	12,000
0.3	3,307.20
0.35	810.9
0.4	148.2

Table 6.2: Wind resource assessment (MW of onshore capacity) in Pennsylvania at different capacity factors. *Source: NREL*

We were able to obtain only four data points directly from NREL to describe wind resource potential (in MW of generation capacity) at different capacity factors, shown in Table 6.2. To estimate the wind resource at other specific capacity factors, we interpolated between these points using a cubic model. The model is described in more detail in Appendix A; our estimated quantities of wind capacity at different capacity factors in Pennsylvania are shown in Table 6.3.

Capacity factor	Cumulative Capacity (MW)
0.25	12,000.00
0.26	9,556.30
0.27	7,500.07
0.28	5,796.42
0.29	4,410.43
0.3	3,307.20
0.31	2,451.83
0.32	1,809.42
0.33	1,345.07
0.34	1,023.86
0.35	810.90
0.36	671.28
0.37	570.11
0.38	472.47
0.39	343.47
0.40	148.20

Table 6.3: Estimated rated capacity at different capacity factors.

Capacity factor	Total Capacity (MW)	Incremental Capacity (MW)	Incremental GWh Generated	Total GWh Generated	LCOE ($/Mwh) @ 6% discount rate	LCOE ($/Mwh) @ 7.5% discount rate
0.40	148	148	519	519	37.11	44.17
0.39	343	195	667	1,186	38.34	45.59
0.38	472	129	429	1,616	39.64	47.08
0.37	570	98	316	1,932	41.01	48.65
0.36	671	101	319	2,251	42.46	50.30
0.35	811	140	428	2,679	43.98	52.05
0.34	1024	213	634	3,314	45.60	53.91
0.33	1345	321	929	4,242	47.32	55.88
0.32	1809	464	1,302	5,544	49.14	57.97
0.31	2452	642	1,745	7,288	51.08	60.19
0.3	3307	855	2,248	9,536	53.15	62.56
0.29	4410	1103	2,803	12,339	55.36	65.10
0.28	5796	1386	3,400	15,739	57.73	67.82
0.27	7500	1704	4,029	19,768	60.27	70.74
0.26	9556	2056	4,683	24,451	63.02	73.88
0.25	12000	2444	5,352	29,803	65.98	77.28

Table 6.4: Capacity and LCOE of wind energy in Pennsylvania, various interest rates and capacity levels

At this point, we can now create a supply curve for wind energy in Pennsylvania. As previously stated, we assume that suppliers with the lowest LCOE enter the market first, followed by suppliers with incrementally higher LCOE. The supply curve thus shows the amount of wind energy (MWh) that we estimate could be supplied in Pennsylvania at different levelized costs of energy. Our estimated supply curve is shown in Figure 6.3 (with the underlying data shown in Table 6.4), under different assumptions regarding the effective discount rate for a wind energy project.

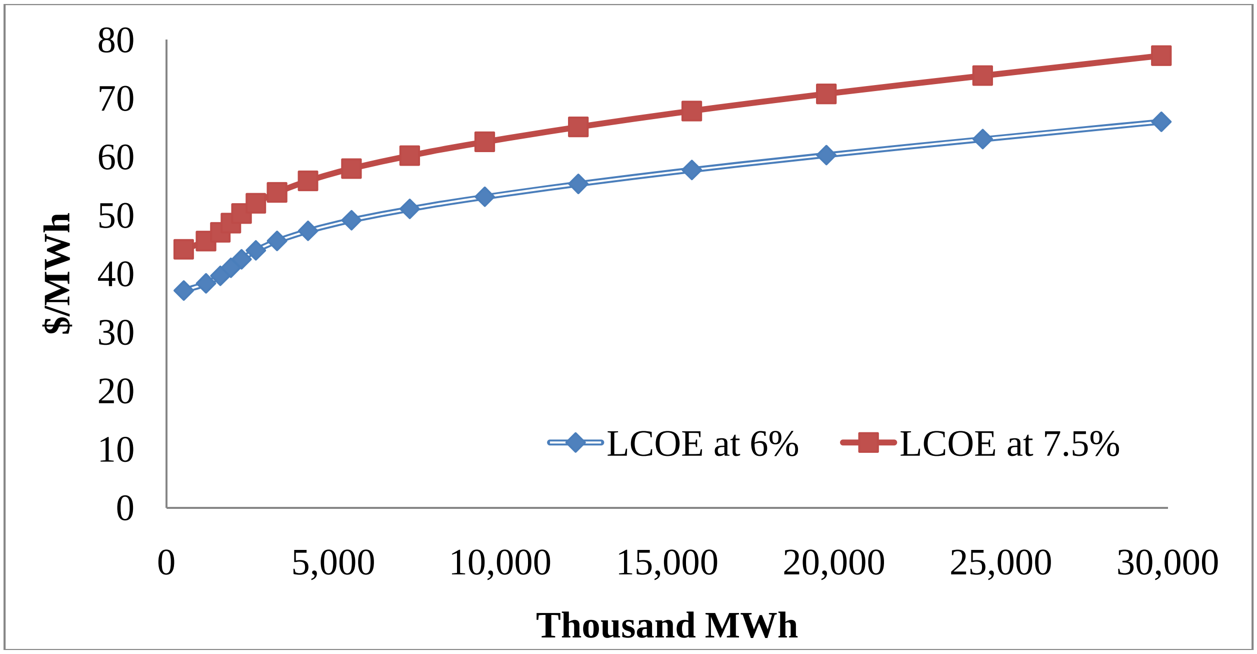


Figure 6.3: Estimated supply curve for Pennsylvania onshore wind

C. The Opportunity Price of Wind Power

As with photovoltaic power, the relevant cost of meeting AEPS requirements with wind power is the "opportunity price" – the market price of the energy replaced by wind power. We use a similar method to estimate the opportunity price of wind energy in Pennsylvania. We base our opportunity price estimates on a node in Western Pennsylvania where data from PJM suggests that wind turbines currently connect to the PJM power grid. We choose the Leadville node in Somerset County. We obtain hourly prices at the Leadville node for 2010. We also obtain hourly wind energy production data for the entire PJM territory for 2010. (PJM does not make production data from individual wind farms public.) Using these figures, we can calculate a weighted average price for wind energy over a monthly or annual basis. The weights we use represent the proportional amount of wind energy generated; we use hourly weights to calculate a monthly average wind energy price (as in Table 5.9, which presents an example for January 2010), while we use monthly weights to calculate an annual average wind energy price (as in Table 6.5). For January, Table 6.5 indicates that the average wind energy price is $42.58/MWh. Monthly average wind energy prices are included in Table 6.6, which also shows an annual average wind energy price of $38.54/MWh.

Hour	Nodal Average Price ($/MWh)	Average Percent of Daily Wind Output	Hourly Contribution to Average Nodal Price ($/MWh)
1	$36.1	4.49	$1.62
2	$38.5	4.49	$1.73
3	$38.9	4.38	$1.70
4	$37.3	4.28	$1.60
5	$35.3	4.27	$1.51
6	$38.6	4.26	$1.64
7	$46.4	4.24	$1.97
8	$44.2	4.19	$1.85
9	$44.7	4.16	$1.86
10	$47.8	3.99	$1.91
11	$52.5	3.87	$2.03
12	$48.2	3.76	$1.81
13	$43.6	3.62	$1.58
14	$43.1	3.6	$1.55
15	$40.2	3.67	$1.48
16	$38.2	3.8	$1.45
17	$39.8	3.95	$1.57
18	$45.8	4.03	$1.85
19	$52.6	4.2	$2.21
20	$49.4	4.41	$2.18
21	$47.4	4.57	$2.17
22	$43.2	4.64	$2.00
23	$37.2	4.59	$1.71
24	$35.6	4.51	$1.61
Total – monthly average nodal price			$42.58

Table 6.5: Calculating the average wind nodal price for January 2010, Leadville node.

Month	**PJM Wind Energy Output (Mwh)**	**Percent of Annual Wind Output**	**Monthly Average Price ($/MWh)**	**Contribution to Annual Average ($/MWh)**
January	935,576	10.11	$42.58	$4.30
February	709,186	7.66	$41.13	$3.15
March	827,028	8.93	$36.04	$3.22
April	968,278	10.46	$34.08	$3.56
May	705,281	7.62	$33.79	$2.57
June	475,079	5.13	$37.66	$1.93
July	381,660	4.12	$48.69	$2.01
August	331,570	3.58	$42.79	$1.53
September	705,443	7.62	$35.03	$2.67
October	1,007,237	10.88	$31.27	$3.40
November	1,090,886	11.78	$34.61	$4.08
December	1,120,649	12.10	$50.46	$6.11
Total	9,257,872	100.00		$38.54

Table 6.6: Calculated annual wind opportunity price, Leadville node

The weighted average wind energy price that we calculate represents the opportunity price of incremental wind energy projects in Pennsylvania. We note that on an annual basis (using prices from the Leadville node in Southwestern Pennsylvania), the opportunity price of wind energy in Pennsylvania is relatively low. This conclusion arises partially because of our choice of node; Southwestern Pennsylvania is a relatively low-price area within PJM. In addition, wind power is generally negatively correlated with electric loads and thus electricity prices. For example, Figure 6.4 shows the relationship between wind power output and electricity price for August 2010. Notice that wind power output is highest between midnight and 6AM, when electricity prices are at their lowest. There are seasonal variations in this relationship, as shown in Figure 6.5. Throughout the year, however, wind energy production in PJM tends to be negatively correlated with electricity demand.

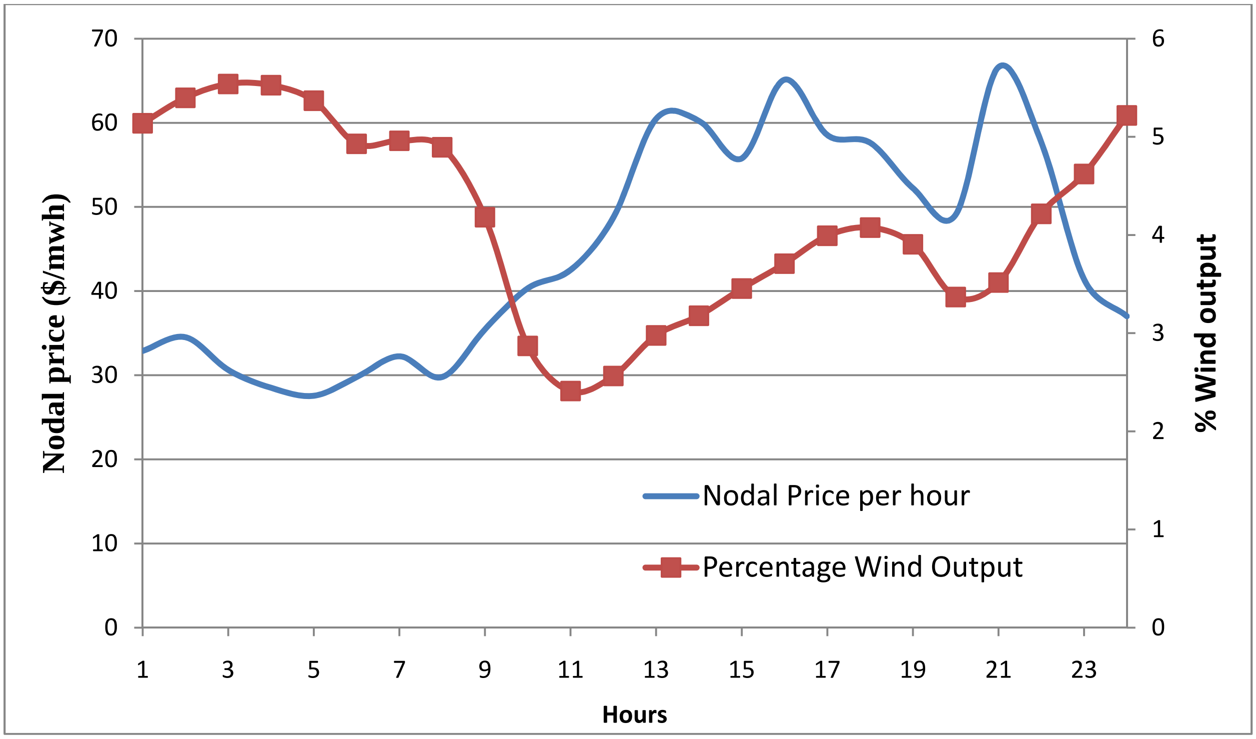


Figure 6.4: Hourly wind energy output and electricity prices at the Leadville node, August 2010.

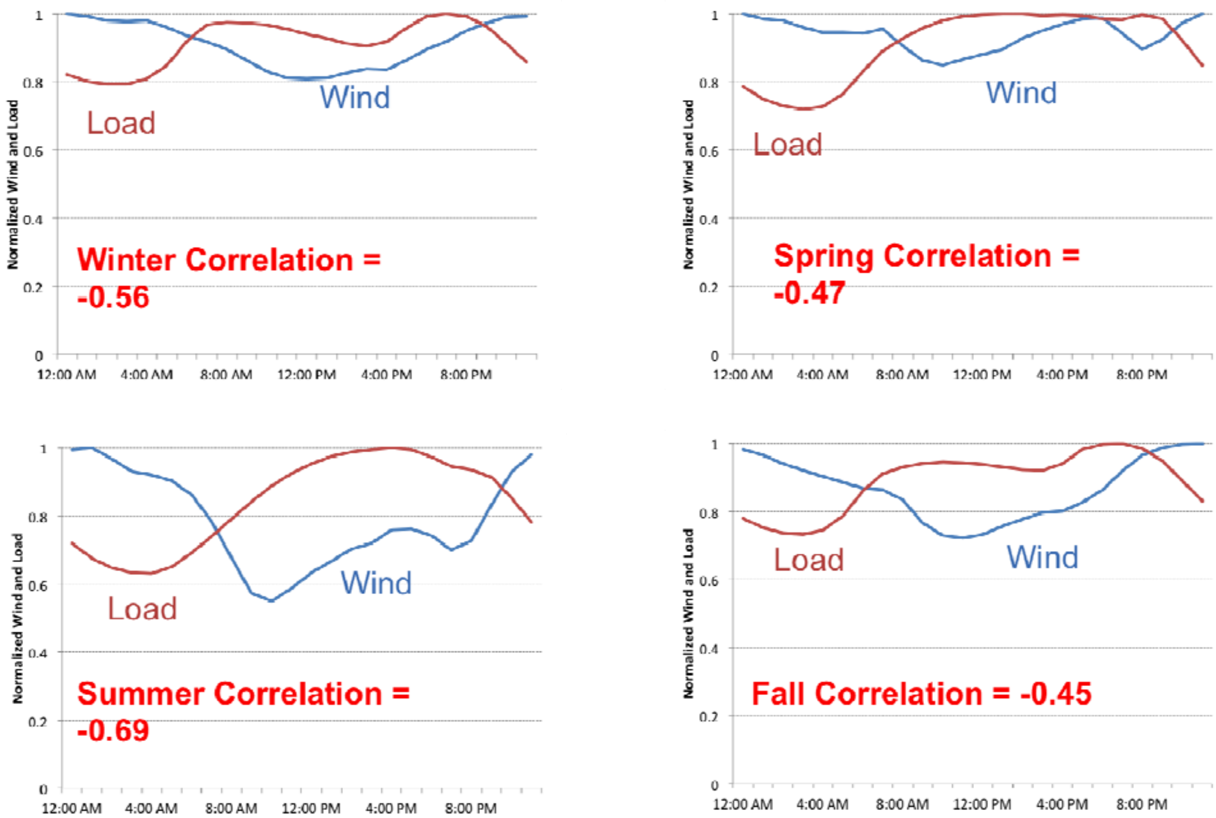


Figure 6.5: Seasonal correlations between wind energy and electricity demand in PJM, 2010. The data series are normalized to reflect relative changes in wind production and electricity demand.

The difference between the LCOE for wind energy and the opportunity price of wind energy provides an estimate of the costs of meeting AEPS requirements with wind energy to Pennsylvania electricity consumers. This calculation is more difficult than the photovoltaic calculation, because the cost of wind power will depend on the amount of wind required. Thus, for simplicity, we will present cost figures for circumstances only when the relevant interest rate is 6 percent per year.[29] Given different quantity levels and our assumption about the existence of the Federal tax credit of $21/MWh, the cost per MWh of incremental wind energy generation investments to Pennsylvania consumers is shown in Table 6.7.

[29] We note that if the LCOE is less than the annual average opportunity price of $38.84/MWh, then wind energy investment would survive in the free market without any of the mandates or subsidies afforded through AEPS. Such investment would benefit Pennsylvania consumers by lowering energy costs, and thus the added cost is zero.

Minimum Quantity (Thous. MWh)	**Maximum Quantity (Thous. MWh)**	**Cost per MWh, 6% interest rate ($/MWh)**	**Cost per MWh, 7% interest rate ($/MWh)**
0	519	$0.00	$5.63
519	1186	$0.00	$7.05
1186	1616	$1.10	$8.54
1616	1932	$2.47	$10.11
1932	2251	$3.92	$11.76
2251	2679	$5.44	$13.56
2679	3314	$7.06	$15.37
3314	4242	$8.78	$17.34
4242	5544	$10.60	$19.43
5544	7288	$12.54	$21.65
7288	9536	$14.61	$24.02
9536	12339	$16.82	$26.56
12339	15739	$19.19	$29.28
15739	19768	$21.73	$32.20
19768	24451	$24.48	$35.34
24451	29803	$27.44	$38.74

Table 6.7 – Wind energy costs per MWh assuming 6% and 7.5 % interest rates and continuation of Federal Production Tax Credit for alternative generation resources

As Table 6.7 indicates, the cost of meeting Pennsylvania's AEPS with wind energy varies greatly, depending on the size of the incremental investment. Meeting AEPS requirements with high-quality wind resources imposes relatively small costs on Pennsylvania ratepayers. Unfortunately, high-quality wind resources are limited in Pennsylvania. As lower-quality wind resources are exploited, meeting AEPS requirements with these resources involves significant costs.[30]

[30] We made similar calculations for off-shore wind to be generated in Lake Erie. We found no circumstances where off-shore wind could compete against on-shore wind, as off-shore wind was always more expensive. For example, using a 50 percent capacity factor and a 6 percent interest rate, we find that the LCOE of wind is approximately $85/MWh. This would not be competitive against land-based wind power in any scenario discussed above. Therefore, we do not present a thorough discussion of the costs of off-shore wind here.

VII. The Cost of Pennsylvania's Alternative Energy Portfolio Standards

Given the work above, we are now in a position to calculate the costs of Pennsylvania's AEPS standards. We first estimate the costs associated with the photovoltaic carve-out portion of AEPS. The first step in estimating these costs is determining the size of the photovoltaic carve-out, as a percentage of total electricity demand in Pennsylvania in a particular year. The total cost of the photovoltaic carve-out is thus the size of the carve-out (kWh) multiplied by the difference between the LCOE for photovoltaic energy and the solar photovoltaic opportunity price that we calculated in Section V.

To determine the cost of payments to wind power suppliers, we first estimate the amount of wind energy demanded to fill AEPS requirements, using the assumptions discussed in Section III. Using the supply curve for wind energy that we derived in Section VI, the market price of new wind energy resources is calculated. The total cost of a wind energy build-out in Pennsylvania would thus be the size of the additional wind energy investments multiplied by the difference between the LCOE for wind energy (the market price at the relevant point on the wind supply curve) and the wind opportunity price that we calculated in Section VI.

Finally, we include estimates of payments to Tier I suppliers other than wind or solar photovoltaic energy. We first determine the amount of energy provided by Tier I suppliers other than wind or solar photovoltaic, and multiply this quantity by the market price of a Tier I credit, which would be determined by the LCOE of wind energy.

With these cost estimates, we then sum the costs of the photovoltaic carve-out, wind energy and other Tier I suppliers to obtain the total AEPS-related cost for each year. Our results are shown below in Table 7.1 for the low PV innovation path and in Table 7.2 for the high innovation path.

The second column in Tables 7.1 and 7.2 is the expected annual electricity consumption in Pennsylvania. This column uses 2009 consumption as a base year and follows the projection of the Energy Information Administration for 1 percent growth in Pennsylvania electricity consumption per year. The photovoltaic quantity required is calculated by multiplying the expected electricity consumption by the photovoltaic carve-out percentage. That number is in turn multiplied by the photovoltaic cost per year, under the various interest rate and innovation assumptions. For the low innovation path, with 6 percent interest rates, the costs of the PV mandate rise steadily from $7 million in 2012 to $97 million in 2012 (Table 7.1). This occurs as the rapid increase in the level of the PV mandate overcomes the reduction in PV costs. On the other hand, with the high innovation path, the cost of the PV mandate reaches in maximum in 2016 or 2017, and falls to $11.5 million (for a 6 percent interest rate) by 2021 (Table 7.2). This occurs because the rate of innovation in PV costs is so great it overcomes the increase in the level of the PV mandate.

Year	Expected PA Electric. Cons. (Thous. MWh)	PV Carve-Out%	PV Quantity (Thous. MWh)	Cost of PV Mandate (6% interest rate, $ million)	Cost of PV Mandate (7.5% interest rate, $ million)
2012	148,103	0.03%	44.4	$6.87	$8.04
2013	149,584	0.05%	74.8	$11.26	$13.18
2014	151,080	0.08%	120.9	$17.70	$20.75
2015	152,591	0.14%	213.6	$30.43	$35.71
2016	154,117	0.25%	385.3	$53.38	$62.69
2017	155,658	0.29%	451.4	$60.80	$71.49
2018	157,214	0.34%	534.5	$69.97	$82.39
2019	158,787	0.39%	619.3	$78.78	$92.87
2020	160,374	0.44%	705.6	$87.21	$102.95
2021	161,978	0.50%	809.9	$97.22	$114.92

Table 7.1: Photovoltaic carve-out costs under a "low innovation rate" scenario

Year	Expected PA Electric. Cons. (Thous. MWh)	PV Carve-Out%	PV Quantity (Thous. MWh)	Cost of PV Mandate (6% interest rate, $ million)	Cost of PV Mandate (7.5% interest rate, $ million)
2012	148,103	0.03%	44.43	5.42	6.41
2013	149,584	0.05%	74.79	7.81	9.30
2014	151,080	0.08%	120.86	10.71	12.87
2015	152,591	0.14%	213.63	15.88	19.33
2016	154,117	0.25%	385.29	23.70	29.29
2017	155,658	0.29%	451.41	22.56	28.45
2018	157,214	0.34%	534.53	21.16	27.44
2019	158,787	0.39%	619.27	18.72	25.27
2020	160,374	0.44%	705.65	15.39	22.10
2021	161,978	0.50%	809.89	11.52	18.46

Table 7.2: Photovoltaic carve-out costs under a "high innovation rate" scenario

Year	Forecast of PA Electric Demand (Thous. MWh)	Tier I Req. (%)	PV Req. (%)	Tier I Req. After Solar (%)	Non-PV Tier I req. (Thous. MWh)	Wind Req. after other Tier I (Thous. MWh)	Wind AEPS Cost, $/MWh	Total Payments to Wind Energy ($million)
2012	148,103	3.50	0.03	3.47	5,139	3,350	$7.06	$23.65
2013	149,584	4.00	0.05	3.95	5,909	4,084	$8.78	$35.85
2014	151,080	4.50	0.08	4.42	6,678	4,816	$10.60	$51.05
2015	152,591	5.00	0.14	4.86	7,416	5,517	$10.60	$58.48
2016	154,117	5.50	0.25	5.25	8,091	6,154	$12.54	$77.17
2017	155,658	6.00	0.29	5.71	8,888	6,912	$12.54	$86.68
2018	157,214	6.50	0.34	6.16	9,684	7,669	$14.61	$112.04
2019	158,787	7.00	0.39	6.61	10,496	8,440	$14.61	$123.31
2020	160,374	7.50	0.44	7.06	11,322	9,226	$14.61	$134.79
2021	161,978	8.00	0.50	7.50	12,148	10,010	$16.82	$168.36

Table 7.3: Cost of Pennsylvania Tier I Wind APS requirements, 2012 to 2021, assuming 6 percent interest rate and continuing of Federal alternative energy tax credit.

The first five steps of the calculation for wind energy costs are laid out in Table 7.3. The first column of Table 7.3 is the relevant year. The second column is the expected electricity consumption in Pennsylvania. This column again uses 2009 consumption as a base year and follows the projection of the Energy Information Administration for 1 percent growth in Pennsylvania electricity consumption per year.

The third column is the Tier I mandate. The fourth column is the photovoltaic "set aside" in the Tier I mandate. The fourth column is the Tier I mandate minus the photovoltaic carve out. The fifth column is the Tier I mandate minus the photovoltaic carve out. The sixth column is the amount of electric energy (MWh) needed to meet the Tier I mandate minus the photovoltaic carve out. The seventh column is the amount of wind energy required, which is equal to the sixth column minus the amount of non-wind, non-photovoltaic Tier I energy assumed above.

The eighth column is the levelized cost of wind energy, assuming a 6 percent interest rate and a continued Federal tax credit of $21/MWh, minus the opportunity price. To gain the costs of the wind power mandate simply multiply the seventh column by the eighth column. This generates the cost of the wind power mandate, which rises from $24 million in 2012 to $168 million in 2021.

Year	Wind Req. after other Tier I (Thous. MWh)	Wind Mandate Cost ($/MWh)	Total Payments to Wind Energy ($million)
2012	3,350	$10.11	$33.87
2013	4,084	$17.34	$70.81
2014	4,816	$19.43	$93.58
2015	5,517	$15.37	$84.80
2016	6,154	$21.65	$133.24
2017	6,912	$21.65	$149.65
2018	7,669	$24.02	$184.21
2019	8,440	$24.02	$202.73
2020	9,226	$24.06	$221.97
2021	10,010	$26.56	$265.86

Table 7.4: Cost of meeting Pennsylvania Tier I AEPS requirements with wind energy, 2012 to 2021. Assumes 7.5 percent interest rate and continuation of Federal alternative energy tax credit.

Year	Other Tier I Supplies (Thous. MWh)	Wind Mandate Cost At 6%, $/MWh	Wind Mandate Cost At 7.5%, $/MWh	Payments assuming 6% interest rate ($ million)	Payments assuming 7.5% interest rate ($ million)
2012	1685.00	$7.06	$10.11	$11.90	$17.04
2013	1718.96	$8.78	$17.34	$15.09	$29.81
2014	1753.59	$10.60	$19.43	$18.59	$34.07
2015	1788.89	$10.60	$15.37	$18.96	$27.50
2016	1824.88	$12.54	$21.65	$22.88	$39.51
2017	1861.56	$12.54	$21.65	$23.34	$40.30
2018	1898.96	$14.61	$24.02	$27.74	$45.61
2019	1937.07	$14.61	$24.02	$28.30	$46.53
2020	1975.90	$14.61	$24.06	$28.87	$47.54
2021	2015.48	$16.82	$26.56	$33.90	$53.53

Table 7.5: Payments to non photovoltaic/wind Tier I suppliers assuming interest rates of 6 percent and 7.5 percent

Using data from Table 7.3, Table 7.4 calculates the cost to Pennsylvania ratepayers of wind power assuming an interest rate of 7.5 percent. This only difference between this and the previous table is the cost per MWh, which is higher with an interest rate of 7.5 percent. In this case, the estimated cost of the wind portion of the AEPS standards rises from $34 million in 2012 to $266 million in 2021.

In addition to payments to photovoltaic and wind providers, the AEPS system also calls for payments to other Tier I suppliers, as described above. Table 7.5 describes those payments. The second column presents our estimate of these supplies, using the method described in Sections 5 and 6. The third and fourth column presents our expectation of market permit prices, given the two different interest rates. The fifth and sixth columns multiply the prices by the quantities to give the estimated payments given interest rates of 6 and 7.5 percent. For an interest rate of 6 percent, the payments rise from $12 million in 2012 to $34 million in 2021. For an interest rate of 7.5 percent, we estimate payments rising from $17 million in 2012 to $53.5 million in 2021.

Year	PV Costs ($ million)	Wind Costs ($ million)	Non PV/wind costs ($ million)	Total Costs ($million)
2012	$6.87	$23.65	$11.90	$42.42
2013	$11.26	$35.85	$15.09	$62.21
2014	$17.70	$51.05	$18.59	$87.34
2015	$30.43	$58.48	$18.96	$107.88
2016	$53.38	$77.17	$22.88	$153.43
2017	$60.80	$86.68	$23.34	$170.82
2018	$69.97	$112.04	$27.74	$209.76
2019	$78.78	$123.31	$28.30	$230.39
2020	$87.21	$134.79	$28.87	$250.86
2021	$97.22	$168.36	$33.90	$299.48

Table 7.6: Cost of Pennsylvania APS program, per year, assuming 6 percent interest rate, low PV innovation path and continuation of Federal alternative energy tax credit.

We are now in position to estimate the total costs of the Pennsylvania AEPS standard as the sum of the photovoltaic, wind, and the non-photovoltaic/wind costs. We calculate these costs for each year until 2021. Assuming an interest rate of 6 percent, and the low innovation path for PVs, these costs are laid out in Table 7.6. Thus, we estimate the cost of the Pennsylvania AEPS standard will rise from $42 million in 2012 to $299 million, in constant dollar terms, by 2021. Assuming an interest rate of 7.5 percent per year, and a low innovation path, we estimate that the cost of the Pennsylvania AEPS standard will rise from $59 million in 2012 to $434 in 2021.

Year	PV Costs ($ million)	Wind Costs ($ million)	Non PV/wind costs ($ million)	Total Costs ($million)
2012	5.42	23.65	11.90	40.97
2013	7.81	35.85	15.09	58.76
2014	10.71	51.05	18.59	80.35
2015	15.88	58.48	18.96	93.33
2016	23.70	77.17	22.88	123.76
2017	22.56	86.68	23.34	132.58
2018	21.16	112.04	27.74	160.94
2019	18.72	123.31	28.30	170.33
2020	15.39	134.79	28.87	179.04
2021	11.52	168.36	33.90	213.79

Table 7.7: Cost of Pennsylvania APS program, per year, assuming 6 percent interest rate, high PV innovation path and continuation of Federal alternative energy tax credit.

Similarly, Table 7.7 estimates the costs of Pennsylvania's AEPS standards, assuming an interest rate of 6 percent and a high PV innovation path. Under this scenario,, we estimate that the cost of the Pennsylvania APS standard will rise, in present-value terms, from $41 million in 2012 to $213 million in 2021. Assuming an interest rate of 7.5 percent and the high innovation path, we estimate that the cost of the Pennsylvania AEPS standard will rise from $57 million in 2012 to $338 million in 2021.

A graph of the costs of the Pennsylvania AEPS program from 2012 to 2021 is presented above in Figure 7.1, assuming the low PV innovation path. We note that the costs of AEPS exhibit a sharp increase after 2015, corresponding to an increased photovoltaic carve-out percentage.

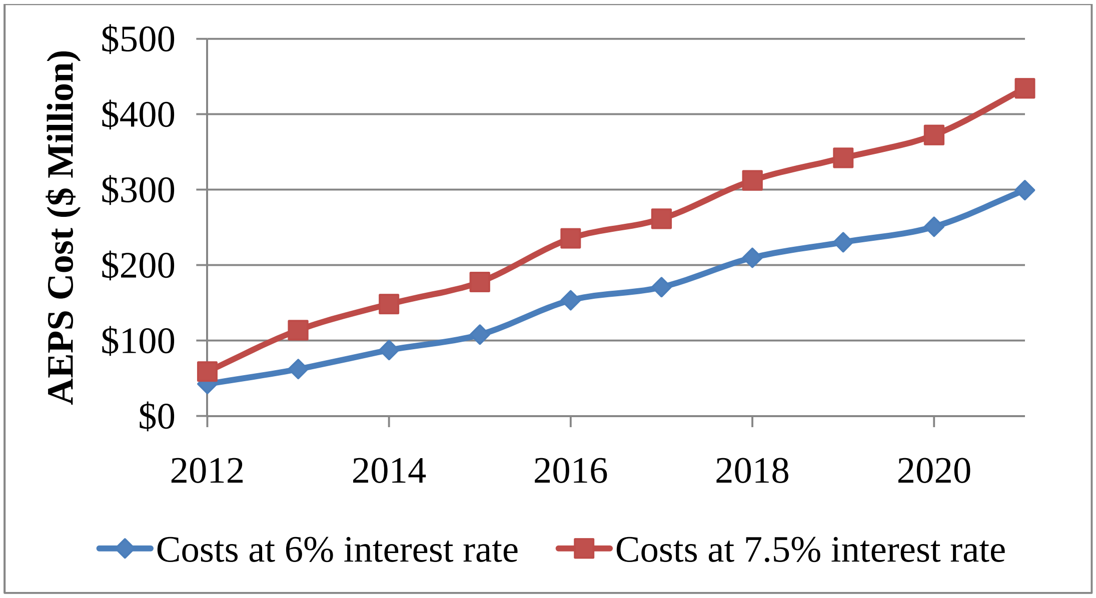


Figure 7.1 – Costs of the Pennsylvania AEPS Program, 2012-2021for low PV innovation path

The PV carve-out, while only constituting a small part of the overall standards, contributes disproportionately to the costs of AEPS compliance under the assumption of a low PV innovation path. To illustrate this, we calculate the PV carve-out fraction of the Tier I requirement, and PV energy's share of the Tier I estimated costs in Table 7.8. As the table indicates, while the PV share of the Tier I requirement goes from 0.86 to 6.25 percent, its share of the costs ranges from 28 to 35 percent after 2015.

Year	Photovoltaic Fraction of Tier I (% kWh)	Photovoltaic Fraction of Tier I costs at 6%	Photovoltaic Fraction of Tier I costs at 7.5%
2012	0.86%	16.21%	13.64%
2013	1.25%	18.10%	11.58%
2014	1.78%	20.27%	13.98%
2015	2.80%	28.21%	20.10%
2016	4.55%	34.79%	26.63%
2017	4.83%	35.59%	27.35%
2018	5.23%	33.36%	26.39%
2019	5.57%	34.19%	27.15%
2020	5.87%	34.76%	27.64%
2021	6.25%	32.46%	26.46%

Table 7.8: Photovoltaic share of requirements and estimated costs, low PV innovation path

Whether these costs address an economic inefficiency is unclear. On the one hand, both wind and photovoltaic energy produce no air emissions while generating electricity.[31] Balancing the intermittent output of wind and photovoltaic with fossil-fuel sources may lessen the emissions-reduction benefits of renewable generation, although by how much is uncertain.[32] In addition, wind, which blows largely at night, would replace relatively dirty coal electricity production. In contrast, daytime PV energy would replace relatively clean natural gas electricity production during peak demand seasons. Thus, assuming the low PV innovation path, replacing the photovoltaic carve-out with an equivalent amount of wind energy would reduce the costs of AEPS considerably, as shown in Table 7.9 below.

[31] The life-cycle air emissions of wind and solar energy are not zero, but are significantly lower than for fossil fuel technologies. See D. Weisser, "A Guide to Life-Cycle Greenhouse Gas Emissions from Electricity Generation," International Atomic Energy Agency, 2010. Available at http://www.google.com/url?sa=t&source=web&cd=4&ved=0CDYQFjAD&url=http%3A%2F%2Fwww.iaea.org%2FOurWork%2FST%2FNE%2FPess%2Fassets%2FGHG_manuscript_pre-print_versionDanielWeisser.pdf&rct=j&q=life%20cycle%20emissions%20wind%20and%20solar&ei=85t2Tv7sMuPZ0QGT-JTHDQ&usg=AFQjCNEu95xk-vQHqLJ98vIW3375CuMr5Q&sig2=qubuge1gVXsiJgW3CRcfKw&cad=rja

[32] W. Katzenstein and J. Apt, "Air Emissions Due to Wind and Solar Power," *Environmental Science and Technology* 43:2 (2009), pp. 253-258.

Year	PV Tier I %	% savings of eliminating PV carve out at 6% interest rate	% savings of eliminating PV carve out at 7.5% interest rate
2012	0.86%	15.5%	12.9%
2013	1.25%	17.0%	10.4%
2014	1.78%	18.8%	12.4%
2015	2.80%	26.1%	17.8%
2016	4.55%	31.6%	23.1%
2017	4.83%	32.3%	23.6%
2018	5.23%	29.6%	22.3%
2019	5.57%	30.3%	22.8%
2020	5.87%	30.7%	23.1%
2021	6.25%	27.9%	21.5%

Table 7.9: Reduced costs from eliminating photovoltaic carve-out, low PV innovation path

Table 7.9 presents the impact of eliminating the photovoltaic carve-out and replacing this requirement with a similar amount of wind energy. Because the photovoltaic requirement is so small relative to the rest of Tier I, we conclude that this shift would does not increase the price per MWh of wind. By increasing the amount of wind, however, it does increase the cost of wind power slightly.

In 2012, the photovoltaic carve out is slightly less than 1 percent of the total Tier I requirement. Eliminating the photovoltaic carve out would save between 13 and 15.5 percent of the cost in that year with no apparent environmental harm. In 2021, the photovoltaic carve is designated as 6.25 percent of the requirement. Eliminating the photovoltaic carve out in that year would reduce costs by between 21.5 and 28 percent, or between $62 and $69.5 million. Figure 7.2 presents this difference graphically.

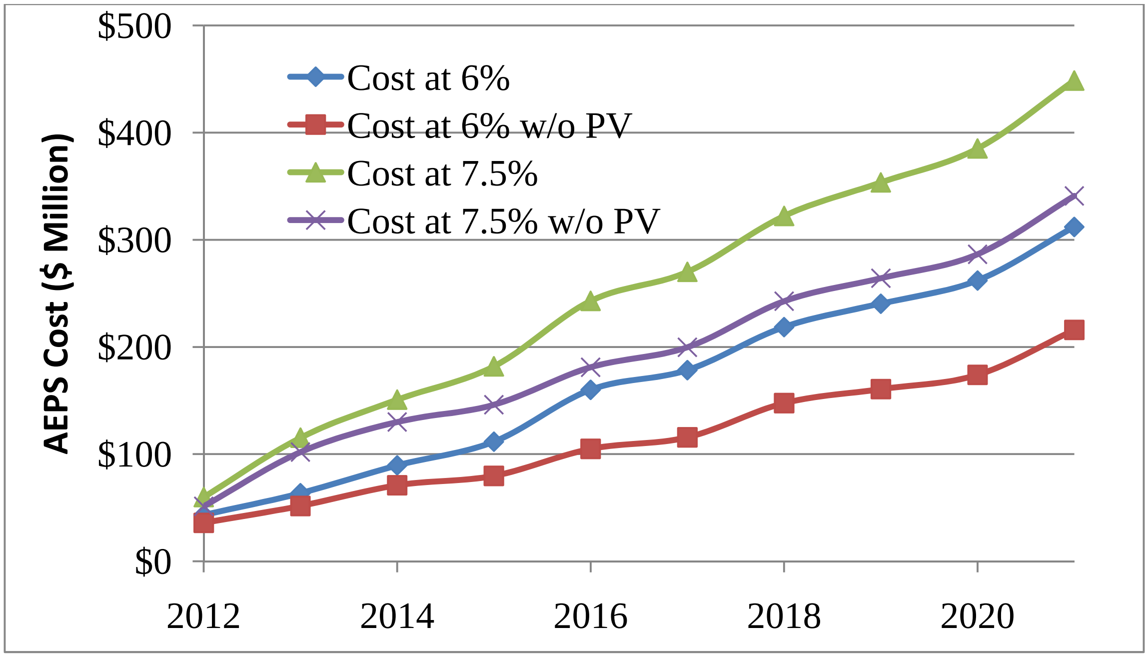


Figure 7.2: Costs of AEPS with and without photovoltaic carve-out

Table 7.10 lays out the costs of the AEPS standards with the high PV innovation path. In these circumstance the costs of PV power comes relatively close to the cost of wind power by 2021. Thus, while the other Tier I costs stay the same, the cost of solar declines dramatically. This results in costs for the AEPS standards of $219 million in 2021 with an interest rate of 6 percent, and $343 million with an interest rate of 7.5 percent.

	6% interest rate		**7.5% interest rate**	
Year	**PV Costs**	**Total Costs**	**PV Costs**	**Total Costs**
2012	$5.423	$40.97	$6.41	$57.31
2013	$7.812	$58.76	$9.30	$109.92
2014	$10.710	$80.35	$12.87	$140.52
2015	$15.883	$93.33	$19.33	$161.28
2016	$23.703	$123.76	$29.29	$202.04
2017	$22.558	$132.58	$28.45	$218.40
2018	$21.156	$160.94	$27.44	$257.26
2019	$18.717	$170.33	$25.27	$274.52
2020	$15.387	$179.04	$22.10	$291.61
2021	$11.524	$213.79	$18.46	$337.85

Table 7.9: Costs of AEPS with high PV innovation path

We have already noted the important of assumptions about the PV innovation path. Other assumptions are important as well. In particular, our cost estimates represent the difference between the levelized cost of energy and the opportunity price of the power that would be generated absent the AEPS standards. Thus, for example, if production of natural gas from the Marcellus Shale formation serves to lower the price of electricity in Pennsylvania, this is turn (by itself) will increase the cost of AEPS standards to Pennsylvania ratepayers.

Our conclusions hinge on other assumptions as well. We assume that the Federal Production Tax Credit, which currently has a limited span, will stay in place indefinitely. Failure by the U.S. Congress to renew the Production Tax Credit would increase the costs of the AEPS to Pennsylvania ratepayers. We also assume that Pennsylvania does not become a major exporter of alternative energy credits to other states. Should exports rise significantly, particularly for wind energy credits, this would increase the cost of the AEPS standards to Pennsylvania ratepayers as higher-cost resources are built-out to serve both the Pennsylvania market and the market for alternative energy credits in other states. We assume that real interest rates, which are historically low, do not rise. Finally, we assume that all the available economical wind sites are developed, abstracting from such issues as construction permits and access to the PJM grid.

VIII. Impact of Alternative Standards on Investment and Grid Reliability

There are other potential impacts and costs of alternative portfolio standards that we do not review here. The first is the potential for "crowding out" of investment in traditional thermal-based electricity sources. Private firms make investments in the hope of turning profits. If there is regulatory induced investment in alternative electricity sources, this will have the (short-run) impact of lowering electricity prices. This effect, however, will rebound, as it will likely reduce market driven investment.

This, by itself, might not be of concern, except for the fact that photovoltaic and wind power are non-dispatchable, and (currently) non-storable in large quantities at competitive costs. Thus, more additional photovoltaic and/or wind power cannot be dispatched should electricity demand be high. Further, there may be times when there is high demand and wind does not blow in the relevant areas, and/or it is cloudy near photovoltaic energy sites.

In electricity systems, demand and supply must be constantly kept in balance. PJM responds to immediate deviations in electricity supply and demand through its ancillary services markets. In these markets, firms are paid money in order to have their plants on "stand-by" to increase or decrease output quickly in case there are shortages. Increasing the amount of wind and photovoltaic power in an electricity grid can be expected to increase the costs of operating the ancillary services market, though by how much is unclear.

IX. Conclusion

The Pennsylvania AEPS mandates the increased utilization of alternative electricity generation resources in Pennsylvania. As AEPS requirements increase, it seems likely that AEPS will have the effect of increasing the utilization of wind energy and solar photovoltaic energy in particular. Because these generation resources have costs that are currently above market prices, policies that promote these generation resources will generally impose costs on Pennsylvanians.

We find that the cost of the state's solar photovoltaic "carve-out" may be is quite high relative to the costs of other resources that qualify under AEPS. The cost of solar photovoltaic power today is nearly an order of magnitude higher than the price of electricity. Unless costs for PV modules continue to decline at historical levels, we estimate that by 2021 the photovoltaic carve-out will represent slightly over 6 percent of the AEPS Tier I mandate, but account for approximately 24 to 30 percent of the costs to ratepayers.

The cost per unit of wind power to ratepayers, on the other hand, is much smaller than that of the solar photovoltaic carve-out, assuming the low PV innovation path. Because high quality wind sites in the state are limited, however, the larger the relevant wind mandate, the higher the price per unit of the wind power mandate. We estimate that the cost of the wind power mandate will rise from approximately $8.50 per MWh in 2012 to approximately $20 per MWh hour, in inflation-adjusted dollars, by 2021.

Using the low PV innovation path assumption, our analysis estimates that the cost of the Pennsylvania AEPS program to rate payers in 2012 will be between $43 and $60 million. This cost will rise to between $312 and $439 million in 2021. We note, however, that these costs could potentially be reduced if the solar photovoltaic carve out was eliminated, or expanded to include lower cost photovoltaic resources (such as solar hot water heating or solar thermal energy) with no apparent cost to the environment. Under our high innovation path scenario for PV, the costs of AEPS standards are considerably lower. We estimate the cost of AEPS standards to Pennsylvania ratepayers at from $42 to $58 million in 2012. We estimate that these costs will rise to between $219 to $343 million in 2021.

Appendix A. Estimating Wind Resources in Pennsylvania

We were able to obtain four data points from NREL to describe wind resource potential (in MW of generation capacity) at different capacity factors, shown in Table 5-4. To estimate the wind resource at other specific capacity factors, we interpolated between these points using a cubic model. The model we use takes the form:

$$Ax^3+Bx^2+Cx+D= y, \qquad (1)$$

where *x* represents capacity factor and *y* represents rated capacity. The terms A, B, C, and D represent the four parameters of the cubic model.

To obtain the simultaneous equations, the values from table 5-4 are substituted into equation 1. This gives a system of four different equations, as follows:

$$A(0.25)^3+B(0.25)^2+0.25C+D= 12{,}000 \qquad (2)$$
$$A(0.3)^3+B(0.3)^2+0.3C+D= 3{,}307.20 \qquad (3)$$
$$A(0.35)^3+B(0.35)^2+0.35C+D= 810.9 \qquad (4)$$
$$A(0.4)^3+B(0.4)^2+0.4C+D= 148.2 \qquad (5)$$

Solving these equations simultaneously, yields A= -5,817,200, B= 6,474,780, C= -2,411,572, and D=301,113. Substituting in these values in Equation 1 above yields

$$-5{,}817{,}200\, x^3 + 6{,}474{,}780x^2 - 2{,}411{,}572x + 301{,}113 = y \qquad (6)$$

Equation 6 allows us to estimate the cumulative wind resource in Pennsylvania for any given capacity factor, as shown in Table A-1. The figures in this table are utilized in the supply curve analysis shown in Section 6.

Capacity factor	Cumulative Capacity (MW)
0.25	12000.00
0.26	9556.30
0.27	7500.07
0.28	5796.42
0.29	4410.43
0.3	3307.20
0.31	2451.83
0.32	1809.42
0.33	1345.07
0.34	1023.86
0.35	810.90
0.36	671.28
0.37	570.11
0.38	472.47
0.39	343.47
0.40	148.20

Table A-1: Estimated wind resource in Pennsylvania at different capacity factors.