Energy Policy 38 (2010) 6820–6829

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

The role of energy efficiency spending in Maryland's implementation of the Regional Greenhouse Gas Initiative

Anthony Paul [a,*], Karen Palmer [a], Matthias Ruth [b,c,d], Benjamin F. Hobbs [e], Daraius Irani [f], Jeffrey Michael [g], Yihsu Chen [h], Kimberly Ross [b], Erica Myers [a]

[a] Resources for the Future, Washington, DC, USA
[b] Center for Integrative Environmental Research, University of Maryland, USA
[c] Engineering and Public Policy Program, University of Maryland, USA
[d] Environmental Policy Program, School of Public Policy, University of Maryland, USA
[e] Department of Geography and Environmental Engineering, Whiting School of Engineering, The Johns Hopkins University, USA
[f] Regional Economic Studies Institute, Towson University, Towson, MD, USA
[g] Business Forecasting Center, Eberhardt School of Business, University of the Pacific, USA
[h] School of Engineering, Social Sciences, Humanities and Arts, University of California, Merced, CA, USA

ARTICLE INFO

Article history:
Received 27 August 2009
Accepted 30 June 2010
Available online 5 August 2010

Keywords:
Climate policy
Energy efficiency
Electricity demand

ABSTRACT

What are the economic consequences of increased state spending on electricity consumption efficiency? The State of Maryland faces this question in deciding how much of its CO_2 allowances auction proceeds (under the Regional Greenhouse Gas Initiative) to devote to such programs. Starting at a base of 25% of the proceeds, we consider the energy savings, emissions reductions, employment, and other impacts of increasing that percentage to 50% and 100%. A series of models – Haiku, JHU-OUTEC, and IMPLAN – are used for the analysis. We conclude that increasing the state's expenditures on energy efficiency programs would result in a decline in electricity consumption in the state and a corresponding decline in expenditures on electricity. Program implementation would lead to net positive growth in statewide economic activity and include growth in both jobs and wages.

1. Introduction

In 2007, Maryland joined the Regional Greenhouse Gas Initiative (RGGI), which is a cooperative agreement among ten Northeastern and Mid-Atlantic states designed to reduce emissions of carbon dioxide (CO_2) from major power generators through a cap and trade program (Regional Greenhouse Gas Initiative, 2005, 2007, 2008). With the first auction of RGGI allowances (permits) held in September 2008 and subsequent auctions held every 3 months since, Maryland is receiving RGGI auction proceeds and must rapidly develop and implement a program to use these funds.

One use for auction proceeds is funding for energy efficiency programs designed to decrease energy use, and in particular electricity use. Such programs could lower electricity bills and thereby partially or fully offset the higher power prices that will otherwise be faced by households and firms under RGGI implementation. Several of the RGGI states are planning to use much or all of their shares of the proceeds for such programs; other uses include direct subsidies to consumer's electricity bills and grants of free allowances to industry.

Maryland has historically been not as aggressive in promoting energy efficiency as other states in the region. For example, in 2006, Maryland spent only 0.001% of State GDP on energy efficiency, compared with 0.01% percent in New York or 0.06% in Vermont. Closing this gap could help the state reduce energy imports, improve environmental quality, and create jobs in the energy efficiency field. In the 2008 session of the Maryland General Assembly, a law was enacted to devote 23% of the state's RGGI proceeds to rate relief through rebate programs and the rest to efficiency (46%), low income electricity assistance (17%), clean energy, education, and climate change (10.5%) programs, leaving the remainder (3.5%) for administrative costs.

This paper presents the methodology and results from an analysis of the environmental, energy, and economy implications that derive from increasing shares of the RGGI auction revenue in support of consumer benefit programs, notably efficiency programs that target end-use consumption of electricity through subsidies to avoided consumption. Specifically, the study examines the following questions. What would be the effects of different levels of spending in Maryland on improvements in efficiency in electricity consumption? These impacts are assessed in terms of electricity demand, electricity prices and expenditures,

* Corresponding author.
E-mail address: paul@rff.org (A. Paul).

0301-4215/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enpol.2010.06.055

RGGI CO_2 allowance prices and revenue, electricity supply in Maryland, generator competitiveness and market power, generation adequacy and transmission import capability, and overall economic impacts within Maryland. How robust are the conclusions for different modeling assumptions about energy markets and market power, and transmission capability?

To answer these questions, this study expands our earlier modeling, research, and analysis of the economic and energy impacts of Maryland joining RGGI (Ruth et al., 2008). Here, we explore the economic and energy impacts of Maryland's use of its RGGI allowance revenues for efficiency improvements in end-use electricity consumption within the state. The paper combines three distinct models that communicate output with each other as schematically shown in Fig. 1, and as described in more detail in the following section.

The Haiku model is a national economic simulation of electricity markets based on market equilibrium concepts. This model can answer questions such as How will Maryland's electrical power prices and fuel mix for power generation change at different levels of energy efficiency investment? This model also provides input data to the other two models.

The JHU-OUTEC model is a regional market equilibrium model for the Pennsylvania–New Jersey–Maryland (PJM) area allowing for market power in the generation sector. JHU-OUTEC stands for Johns Hopkins University Oligopoly Under Transmission and Emissions Constraints. The model helps to answer questions such as How is market power of generation companies affected by Maryland's investment in energy efficiency and changes in the transmission grid?

The IMPLAN model is an input–output model that takes into account changes in employment levels, among other important economic indicators. This model helps to answer questions such as How will different levels of energy efficiency funding from RGGI affect the average annual electricity bill and the state's economy, including tax revenues and employment?

The baseline assumption for the three models is the use of twenty-five percent of RGGI auction revenue for efficiency improvements. Twenty-five percent is the minimum fraction of allowance revenue that must be dedicated to a "consumer benefit or strategic energy purpose" (RGGI, 2005). The resulting energy and economic implications are compared with two scenarios of higher expenditures at 50 and 100% of auction revenue. All other parameters of RGGI and electricity markets in Maryland and the other states are held constant across these three scenarios. Each scenario assumes 100% of RGGI allowance allocation is through auction (i.e., all allowances are allocated through the auction).

2. Models

2.1. National power market model: Haiku

The Resources for the Future (RFF) Haiku Electricity Market Model is designed to simulate changes in electricity markets that result from environment regulations and other types of policies that affect electricity markets in the United States (for model documentation, see Paul et al., 2009a). The adoption of the RGGI program will affect the incentives and the economic behavior of participants in electricity markets, including producers of electricity and reserve services, transmission grid owners, and electricity consumers. In turn, changes in incentives affect various output measures such as electricity prices and emissions from electricity production. The Haiku model captures these effects and has been enhanced to simulate public programs for energy efficiency improvements.

There is a burgeoning academic literature on the public financing of efficiency improvements in end-use electricity consumption. Most of the models that appear in the literature are "bottom-up", characterizing electricity end-use technologies by their operational and cost parameters. These models are ideal when data are abundant and the interactions between technologies and those who adopt them can be well characterized through time. However, the variety of end-use technologies for electricity consumption is vast and the technologies that will emerge in the coming decades are difficult to anticipate. Furthermore, the characterization of consumer behavior with respect to electricity end-use technology is fraught with problems as consumers often fail to make technology choices that accord with the economic theory that underpins such models and the limited data that are available to parameterize them. Also, many end-use electricity consumption technologies are long-lived investments that affect electricity markets for many years after the technology choice is made. Current bottom-up technology type models generally do not perform well in capturing the capital dynamics that are introduced by such long-lived investments.

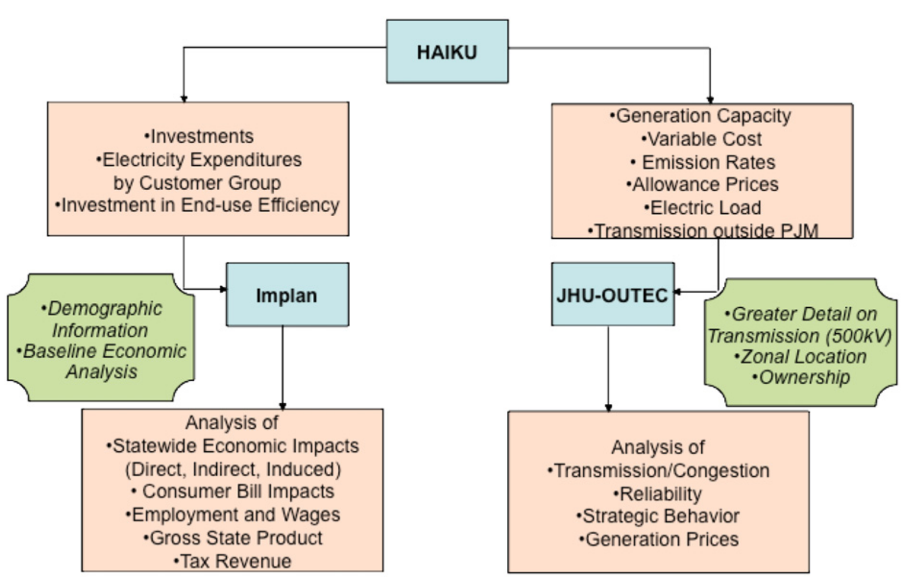


Fig. 1. Model elements, data, and information flows.

Nor do they represent feedback effects in which the price elasticity effects resulting from the changed supply-demand conditions could either magnify or partially counter-act the direct impacts of the energy efficiency programs.

This study utilizes a new "top–down" approach to project the effects of public financing for efficiency programs. A functional form for demand modeling, known as partial adjustment (Houthakker and Taylor, 1970), is used in this study. The partial adjustment demand system finds annual electricity demand by customer class given a sequence of electricity prices. The system is dynamic in that the electricity price at any time t_0 is one of the determinants of demand at all subsequent times $t > t_0$. The model simultaneously captures the short- and long-run price elasticities of electricity demand and is implemented inside of Haiku to project demand using the parameterized functions and endogenous electricity prices. The demand functions operate on annual state-level data. For details of the partial adjustment demand system, see Paul et al. (2009b).

An issue in market-based approaches to environmental regulation, such as the use of tradable emissions allowances, is how the allowances are allocated to facilities or how the publicly owned auction or tax revenue is allocated. A related issue is whether some portion of the allowances should be allocated to specific purposes to provide special incentives. The Demand Conservation Incentive (DCI) in Haiku provides for the allocation of a portion of allowance revenue to consumers in the form of a subsidy to energy conservation. The DCI module returns the amount of electricity saved per annum (kWh/yr) based on an annual stream of funding ($/yr) and a set of endogenous variables, including retail electricity prices and natural gas prices. In equilibrium, the DCI mechanism lowers electricity consumption and retail electricity price.

In each period, we calculate electricity demand as a function of the endogenously determined retail electricity prices and the slope and location of the demand curve. This is the baseline level of demand, which is altered in each period due to DCI-induced reductions. The core concept of the DCI is that consumers will be paid a specific dollar amount for each MWh they conserve beyond the pre-determined baseline of consumption. The payment per MWh is endogenously determined each period based on the amount of allowance revenue and the slopes and intercepts of the demand curve. Consumers will choose to accept the DCI payment rather than using electricity if the money is worth more to them than the energy services derived from another MWh of consumption. The subsidy to conservation effectively increases the cost of consumption, thus lowering demand for electricity. We specify partial adjustment electricity demand models, so that a DCI program that reduces consumption in this period will subsequently lead to lower consumption in the next period, all other things equal. Consumers can be thought of as reducing demand in response to the DCI either through behavioral modifications, or investment in energy efficient capital.

Subsidy programs such as the DCI described here are constrained by several administrative factors. In our analysis we account for three of these following factors: the cost of program administration, efficiency funds that are captured by free riders (those who would have made efficiency enhancing investments or behavioral changes anyway in the absence of the program), and the portion of the retail electricity market that is inaccessible to the administrator.

These are captured in Haiku according to Eqs. (1)–(3). These functions show the amount of demand reductions delivered by consumers for a DCI of D $/MWh, given a simplified electricity demand function and an achievable fraction of demand reductions (the percent of potential reductions that the regulator is able to obtain through the program). The amount of money the program administrator must spend to achieve these reductions is given by Eq. (3), and incorporates the effects of having to spend some of the money on administrative costs, which do not go to consumers, and being unable to distinguish free riders from other program participants:

$$Q_0 = AP^{\varepsilon} \tag{1}$$

$$Q_R = Q_0\left[1-\left(1+\frac{D}{P}\right)^{\varepsilon}\right]Ach \tag{2}$$

$$S = \frac{DQ_R}{(1-FR)(1-Admin)} \tag{3}$$

where Q_0 is the electricity demand in the absence of DCI [MWh], A the electricity demand covariates except for electricity price, P the retail electricity price [$/MWh], ε the short-run price elasticity [dimensionless], Q_R the demand reductions achieved by DCI [MWh], D the DCI payment [$/MWh], Ach the achievable percentage of economic reductions [dimensionless], S the government spending on efficiency program [$], FR the free-rider rate [dimensionless], and $Admin$ the administrative cost rate [dimensionless].

Haiku is a national model that divides the continental US. into 21 regions, with Maryland as one of the regions. The system of Eqs. (1)–(3) is defined for a single year in a single region and the variables in the equation will generally vary across both dimensions. The exceptions to this rule are the three cost factors *Ach*, *FR*, and *Admin*, which are assumed constant across the nation and in time. *Ach* takes the value 60%, *FR* is 20%, and *Admin* is 40%. The other exogenous parameters, ε and A, are defined according to Paul et al., 2009b.

2.2. Regional oligopolistic power market model: JHU-OUTEC

Haiku's national scope accounts rigorously for interactions between the Maryland power market and all other power markets in the US. This allows for careful consideration, for instance, of whether increases in fossil fuel use in other states would partially or fully offset CO_2 emission reductions in Maryland.

This scope is made possible by certain simplifications. One is Haiku's assumption that generators behave in a perfectly competitive manner. However, large generation companies in transmission-constrained areas such as Maryland may behave strategically, raising prices and altering the patterns of electric generation and consumption. Another simplification is Haiku's approximation of the electric power network as a "path-based" network in which power can flow along the least expensive path between source and sink. Haiku also treats Maryland and neighboring states as single nodes in the network, rather than considering within-state transmission bottlenecks. These grid simplifications disregard the fact that power flows along all parallel paths between source and sink, satisfying Kirchhoff's voltage and current laws.

These simplifications could, in theory, distort the results of our study in several ways. The tighter transmission constraints resulting from a more realistic transmission representation might mean, for instance, less "leakage" of CO_2 emissions to neighboring regions, as imports might be more constrained. If power exchanges are more limited, then energy efficiency programs within Maryland would have a larger effect on power prices in the state, as imports would have a smaller buffering effect. Finally, under oligopoly, the energy efficiency programs might have an additional benefit of mitigating market power by lessening the benefit to generators of raising prices, as there would be fewer sales for which generators would receive higher prices.

To assess whether these simplifications might significantly impact our answers to the questions posed in the introduction, we also apply a detailed regional-level model that includes a more realistic representation of transmission flows while considering potential strategic behavior by electric generators. The Johns Hopkins University Oligopoly Under Transmission and Emissions Constraints model (JHU-OUTEC) is a computational game-theoretic model that includes the so-called "linearized DC load flow" model of transmission flows (Chen and Hobbs, 2005). In this model, real power flows satisfy analogues of Kirchhoff's laws (Schweppe et al., 1988), but reactive power flows and resistance losses are disregarded, and voltage magnitudes are assumed to be constant. This approximation is now used widely in detailed models of competitive and oligopolistic power markets (Ventosa et al., 2005). JHU-OUTEC's representation of strategic behavior is based on the widely used notion of Cournot competition, in which generators optimize their sales in each sub-market assuming that other generation companies do not change their sales strategies. The transmission-constrained Cournot framework is frequently used to project power market outcomes under policy and structural changes (e.g., Hobbs and Helman, 2004; Yao et al., 2008). JHU-OUTEC has been previously subjected to validation tests against PJM market outcomes (Chen and Hobbs, 2005).

JHU-OUTEC separates Maryland into four nodes based on flow patterns and network constraints (Chen and Hobbs, 2005). One zone is Delmarva Power and Light (DPLC), which includes Delaware and is recognized by PJM as a separate constrained zone (or Local Demand Area—LDA) in its future capacity market. PJM's Reliability Pricing Model (RPM) also recognizes central Maryland and the District of Columbia (the PEPCO and BGE service territories) as a separate LDA within RPM. This zone is further divided into northern and southern halves (designated BGE_2 and BGE_PEPCO, respectively). Finally, western Maryland is separated out (designated here as APMD, the Allegheny Power service territory within Maryland). Justifying this is an analysis of PJM Locational Marginal Prices (LMPs) from selected buses in APMD and PEPCO that shows that PEPCO's hourly prices are statistically higher than those of APMD. Also included in JHU-OUTEC are the neighboring states of West Virginia, Virginia, Pennsylvania, New Jersey, and the District of Columbia; thus, unlike Haiku, interactions with other US. power markets are disregarded.

To maintain consistency with the Haiku analysis, the estimated generating capacity for the future years (i.e., 2010, 2015, 2020, and 2025) from Haiku was directly incorporated in the JHU-OUTEC model. The same operating capacity for each season was maintained for each type of plant. However, it is necessary to disaggregate the Haiku model generators to 17 individual zones and 13 owners. These owners include 10 large companies that can behave strategically and a price-taking "competitive fringe". The location and ownership of existing generators by zone were identified using public data sources. To ensure an appropriate representation of the potential for market power under the current ownership, it is assumed that operational decisions (generation and sale) are controlled by the parent company, replacing any subsidiaries with the corresponding parent company. New capacity that Haiku projects for construction is allocated to each zone in proportion to existing generation by type and ownership. If this procedure results in unrealistically small capacity additions, those amounts are instead distributed among other owners or zones, as appropriate.

There are variables other than generating capacity that are treated by JHU-OUTEC as exogenous and taken from Haiku output. These include non-fuel variable operations and maintenance costs, emissions allowance costs, and fuel costs. The shadow prices of emissions arising from the Maryland Healthy Air Act are obtained endogenously, since all affected plants are inside of JHU-OUTEC.

One challenge in coordinating Haiku and JHU-OUTEC is the distribution of spatially aggregate regional electricity load data from Haiku to the specific zones in JHU-OUTEC model. For simplicity, load was allocated to the nodes in JHU-OUTEC in proportion to PJM historical experience (PJM, 2001).

The same number and duration of periods used by Haiku (12 periods per year of varying length) are used here. Linear demand functions with -0.2 elasticity are assumed, but are shifted downwards to account for the difference between wholesale and retail prices for energy (the latter including distribution costs, for example). Adjustments are also made for distribution losses (about 6%). Finally, JHU-OUTEC assumes that quantity demanded in a given period is a function only of price in that period, whereas Haiku has more complicated relationships (e.g., Haiku averages marginal costs over periods within a season).

Network data, including transmission capacities (thermal or surge impedance loading (SIL) limits, as appropriate) and reactances required for deriving the power transmission distribution factors (PTDFs) used in the DC approximation, were obtained from the PowerWorld website (PowerWorld, 2003). Only the 500 kV grid is considered, which is the backbone of the PJM system. In 2015, additional transmission capacity is assumed to come on-line. Information on the capacity and reactance of those lines was obtained from publicly available sources.

As is well known, the extent to which a supplier can benefit from exercising market power depends on the degree to which it is pre-committed, through forward contracts or vertical integration, to providing a particular amount of energy to the market. Because of the lack of publicly available data on forward contracting positions, the model assumes the extreme bounding case of no forward contracts. This results in the largest price mark-ups under the oligopoly assumption. Comparing these bounding results to the competitive case provides an upper bound to the effects of assuming oligopoly rather than competition when answering the questions addressed by this study. JHU-OUTEC is used in both the perfect competition and Cournot oligopoly modes. Comparing the former runs to the Haiku results allows us to investigate whether Haiku's representation of the transmission grid affects the conclusions of this study. Then comparing the perfect competition and Cournot results permits an assessment of the impact of strategic competition assumptions on the results.

2.3. IMPLAN

In order to quantify the economic impact of joining RGGI, the IMPLAN input/output model is used (Minnesota IMPLAN Group, 2006). It enumerates the employment and fiscal impact of each dollar earned and spent by the following: employees of the new business, other supporting vendors (business services, retail, etc.), each dollar spent by these vendors on other firms, and each dollar spent by the households of the new business' employees, other vendors' employees, and other businesses' employees.

To quantify the economic impact of a new business entering into an area, economists measure three types of economic impacts: direct, indirect, and induced. The direct economic effects are generated as new businesses hire workers to fill new positions. The indirect economic impacts occur as new firms purchase goods and services from other firms. In either case, increase in employment generate corresponding increases in household income—as new job opportunities are created and income levels rise. This drives the induced economic impacts that result from households increasing their purchases at local businesses.

The centerpiece of an economic impact study is the classification of impacts. In the case of the RGGI impacts, direct impacts include the creation of jobs in specific industries and businesses. Indirect impacts measure the positive effect on the economy resulting from businesses selling goods and services to households. Induced impacts include the effects of increased household spending resulting from direct and indirect effects.

Indirect and induced impacts are estimated by applying multipliers to direct impacts. Multipliers are factors that are applied to a dollar expended towards a particular use. These factors estimate the total value of that dollar as it moves through the economy. For instance, suppose a dollar is spent in a certain industry. That dollar will increase the number of jobs in that industry by a certain amount. Furthermore, some of the money will go to pay the increased earnings in that industry, resulting in higher personal income. In turn, consumers will spend a share of that increase in personal income. Thus, the ultimate impact of a dollar – initially spent in a certain industry – is greater than its direct impact on the earnings of that industry. Multipliers are industry-specific factors that estimate the value of a dollar spent in an industry, including not only its direct impacts, but also its indirect and induced impacts.

The input data for the IMPLAN model, which included the Demand Conservation Incentive (DCI) expenditures, household and commercial savings due to lower utility bills, and the surplus as well as the disinvestment in power plants, were drawn from the analysis conducted by Haiku and JHU-OUTEC. To transform these data into the direct inputs into the IMPLAN model, the impacted industries had to be identified first as well as distributing the savings across households and types of commercial energy users.

The determination of how the DCI expenditures would enter into the state economy was a two step process. As much of the DCI expenditures were focused towards energy efficiency gains in the home and businesses through the addition of new windows, HVAC upgrades, better lighting, etc., a commercial and residential construction reference guide was accessed. The guide provided the costs as well as a breakdown by type of cost – wholesale, plumber, HVAC, architecture fees, etc. – for these types of projects for both commercial and residential. The allocation of DCI expenditures was in three sectors: construction, wholesale, and professional services. The construction sector is the sector responsible for all of the installation activity, the wholesale sector is the impacted by the purchase of the energy saving devices from windows to light bulbs, and the professional services sector is identified with the architects who will provide the design services for the retrofits as well as new buildings.

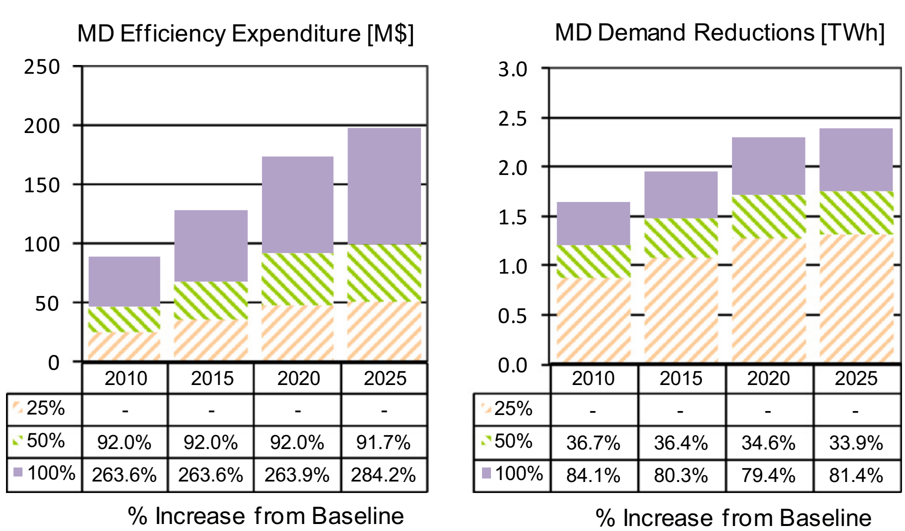
The energy savings realized by the residential were allocated across households on the basis of income and energy usage. For the commercial sector the energy savings were allocated across industry sectors on the basis of energy usage. The energy savings were treated for both the residential and commercial sectors as additional expenditures by each sector and by each household by income category in IMPLAN. The surplus and the disinvestment in power plants were treated as a negative expenditure on behalf of the public sector and the power plant sector in IMPLAN.

One of the shortcomings of the IMPLAN model along with other static input–output models is that the model assumes that supply curve for inputs is perfectly elastic, implying no price effects associated with the rising demand. However, given the relatively small scale of these expenditures in comparison with the Maryland's Gross State Product, the price effects will likely be very small if not inconsequential.

3. Results

3.1. Efficiency program costs, demand reductions, and electricity consumption

RGGI allowance revenue spending for efficiency improvements in end-use electricity consumption will reduce electricity consumption in Maryland. The magnitude of this effect will grow over time as the value of RGGI CO_2 allowances increases. RGGI allowances will increase in value (see Fig. 7) because of anticipated growth in electricity demand in the RGGI region and the tightening of the RGGI CO_2 emissions cap beginning in 2015. The amount of spending on end-use efficiency in each scenario and the associated amount of demand reductions purchased in each simulation year are shown in Fig. 2 with total efficiency spending in the left hand graph and associated purchased energy savings in the right hand graph. Note that efficiency spending does not vary strictly in proportion to the share of allowance revenue being spent on efficiency. For example, in 2010 under the



	2010	2015	2020	2025
25%	-	-	-	-
50%	92.0%	92.0%	92.0%	91.7%
100%	263.6%	263.6%	263.9%	284.2%

	2010	2015	2020	2025
25%	-	-	-	-
50%	36.7%	36.4%	34.6%	33.9%
100%	84.1%	80.3%	79.4%	81.4%

Fig. 2. Total spending on energy efficiency and contemporaneous reductions in electricity demand in Maryland.

baseline scenario (25% efficiency spending) $24 million is spent on efficiency but in the 100% efficiency spending scenario only $89 million is spent on efficiency. This relationship is generally not proportional because greater spending on efficiency will have an effect on the RGGI allowance price, which is discussed below, and thus on allowance revenue.

The right hand side of Fig. 2 clearly shows that greater spending on efficiency enables greater purchases of demand reductions. Not unexpectedly, demand reductions directly attributable to efficiency spending in any given year increase less than proportionately with spending. For example in 2020, efficiency expenditures under the 100% scenario are 3.6 times as large as in the 25% scenario, but the purchased savings are only 1.8 times as large as in the baseline scenario. This result occurs because the next megawatt hour of demand reduction becomes more expensive as the amount of megawatt hour reductions being purchased increases.

The demand reductions in the right hand graph of Fig. 2 represent the immediate megawatt hours of avoided consumption from the efficiency expenditures from the left hand graph in the corresponding year on the horizontal axis. The full stream of demand reductions that are achieved by the efficiency expenditures is greater than these immediate reductions because electricity consuming capital goods are long-lived. The lifetime reductions are calculable using the model parameters to net out the electricity market equilibrium effects of efficiency investment and they are shown in the left hand side of Fig. 3.

One measure of the cost of a state program that funds efficiency measures for end-use electricity consumption is the cost per unit demand reduction, including the demand reductions that accrue through the lifetime of the capital, in periods after the initial investment. The quotient of the efficiency expenditures in the left hand side of Fig. 2 and the lifetime reductions shown in the left hand side of Fig. 3 are a measure of the average cost of efficiency reductions that can be expected under the modeled scenarios of efficiency spending. These values are shown in the right hand side of Fig. 3 and suggest that all of the scenarios of efficiency spending analyzed here will likely yield gains for consumers in power markets since even an efficiency cost of $20/MWh avoided is well below the retail electricity prices that will prevail in Maryland. Comparisons such as this should be made with caution however, as the marginal cost of these lifetime electricity savings is higher than the average cost.

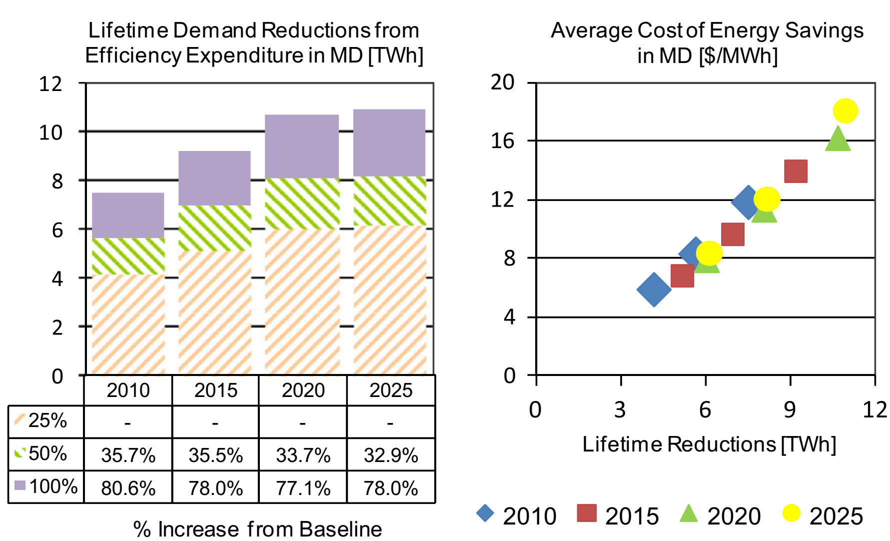
The failure of utilities to take up such cost-effective investments, even in the absence of public funding, may be driven by the historic coupling of sales volume and revenue in Maryland's retail electricity markets. In 2007, the Maryland Public Service Commission approved decoupling for the three largest investor-owned utilities in the state and the expectation is that this will engender cost-effective energy efficiency investments by utilities. If this is borne out as expected, public funds for energy efficiency may crowd out private investments.

The electricity consumption reductions that will follow efficiency expenditures using RGGI allowance revenue will accumulate through time as reductions are persistent in long-lived capital and an increasing stream of funding will continually purchase new reductions in each subsequent year. In comparison with the entire electricity market in Maryland, the effects of efficiency funding on consumption will be small, but it is clear that increasing efficiency funding will lead to marginal reductions. The left hand panel of Fig. 4 shows the projected electricity consumption in Maryland in each of the model scenarios. Increasing the share of revenues spent on efficiency from the baseline of 25 to –50% will reduce demand for electricity by 1.3% annually in 2015 and 2.6% annually in 2025. If 100% of the allowance revenues are spent on efficiency, demand will be 4% below baseline levels in 2015 and nearly 6% below by 2025. The decline in consumption in the 25% scenario that occurs between 2010 and 2015, but not in subsequent years, is the result of projected electricity consumption in the absence of any efficiency funding. This reference case scenario yields only a small increase in consumption between 2010 and 2015, but larger annual increases thereafter.

These demand reductions would contribute to achieving the goal, set forth under the EmPower Maryland plan (Maryland Energy Administration, 2008, Maryland General Assembly, 2008), of reducing *per capita* electricity consumption in the state by 15% from the 2007 level by 2015 as shown in Fig. 3. At a spending level of 25% of RGGI allowance revenue, Maryland will reduce per capita electricity consumption by 7.4% from the 2007 level, or nearly half of the EmPower Maryland goal. Greater spending will reduce per capita consumption further, by 8.7% under 50% spending and by 11.2% if all allowance revenue is spent on electricity consumption efficiency.

3.2. Electricity prices and expenditures

Increasing the share of allowance revenues devoted to energy efficiency will have a substantial effect on electricity



	2010	2015	2020	2025
25%	-	-	-	-
50%	35.7%	35.5%	33.7%	32.9%
100%	80.6%	78.0%	77.1%	78.0%

Fig. 3. Electricity demand reductions and average cost of energy savings in Maryland.

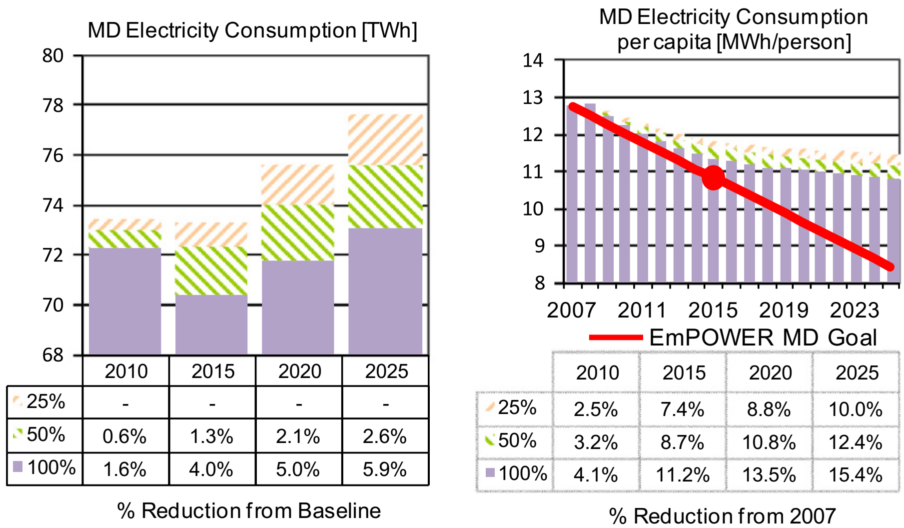


Fig. 4. Maryland electricity consumption and the EmPOWER Maryland goal.

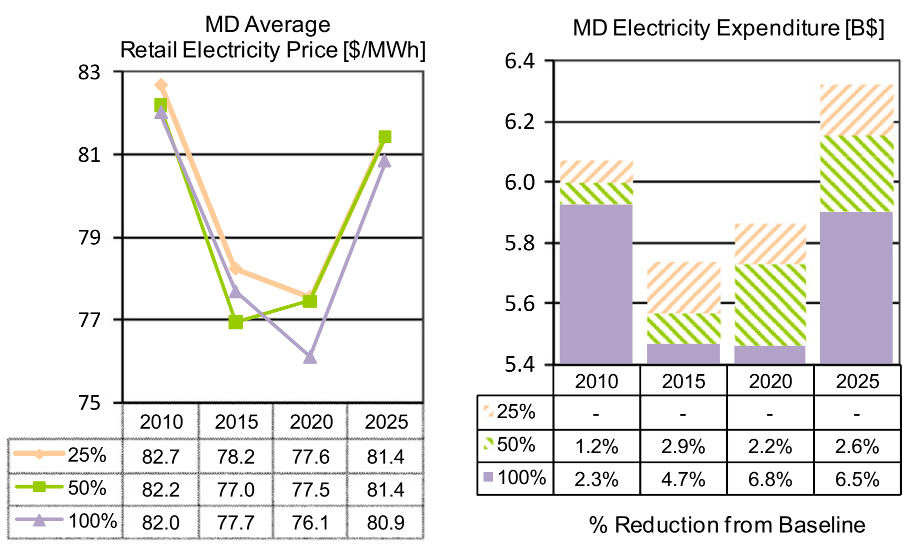


Fig. 5. Average retail electricity price and electricity expenditure in Maryland.

consumption, but very little effect on the average price of retail electricity in Maryland or on the price paid by any single customer class. The left hand side of Fig. 5 shows the projected average retail electricity prices for Maryland consumers under each model scenario. In every year the prices for the expanded efficiency funding scenarios are within 2% of the baseline prices and they should be interpreted as essentially constant in the level of efficiency expenditure. The retail electricity price in Maryland is not more sensitive to efficiency spending because Maryland is embedded within the PJM power market. Since the Maryland power grid is extensively linked to its neighbors, any demand reductions in Maryland will engender declining marginal generation in Maryland and beyond. If Maryland were not linked, then local marginal generation costs would decline even further, while foreign costs would not change. This absorption of program benefits outside the local program area will be a characteristic of any program that is administered on a power grid that is linked to non-participant regions. This is not evidence of net emissions leakage, but simply demonstrates the PJM market equilibrium effects that dominate Maryland's power markets.

Although efficiency spending cannot be expected to yield benefits to consumers via price effects, it does yield benefits via reduced electricity consumption. These benefits accrue through reduced electricity bills. The right hand side of Fig. 5 is a projection of retail expenditure on electricity in Maryland under each scenario. Expenditure is linear in price and so the pattern of expenditures over time closely mirrors the electricity price pattern. Expenditure is monotonic in efficiency funding with funding beyond the baseline level capable of reducing aggregate Maryland electricity bills by more than 5% by the next decade.

3.3. *Electricity supply and RGGI allowance prices*

The changes in electricity consumption in Maryland brought about by different levels of efficiency expenditure can lead to changes in the aggregate amount of generation in the state. Electricity generation in Maryland will fall under increased levels of state funding for efficiency measures, as illustrated in the left-hand panel of Fig. 6. In the 50% scenario, these reductions will

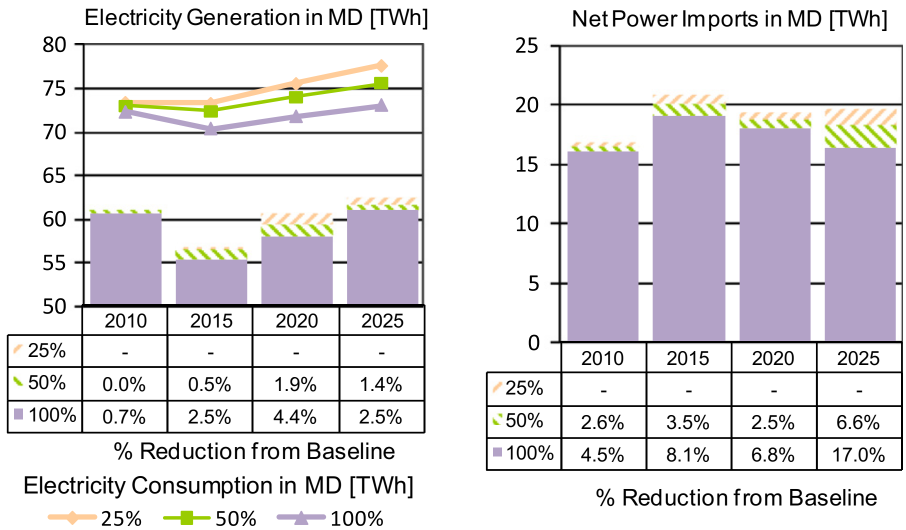


Fig. 6. Electricity generation and imported power in Maryland.

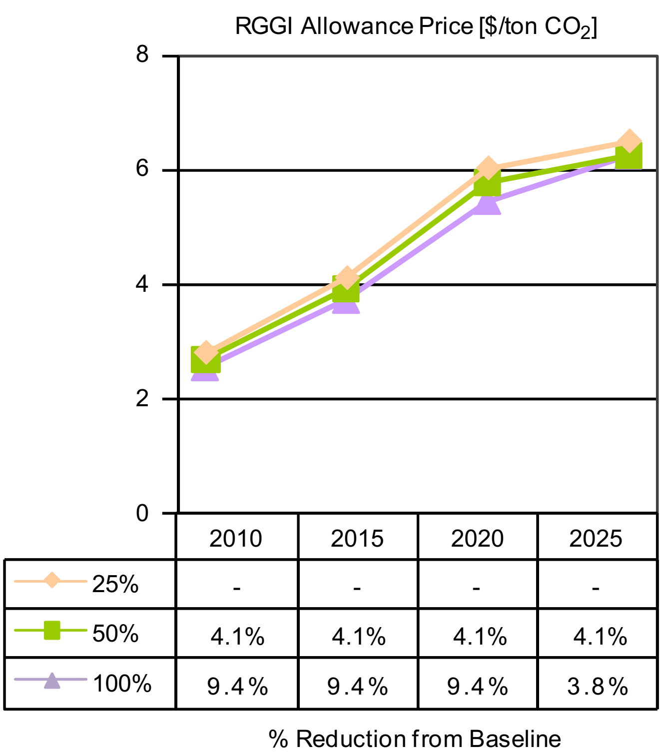


Fig. 7. RGGI allowance price.

be less than 2% of the baseline level and under the 100% scenario the reduction could reach nearly 5% of baseline generation. The left-hand panel of Fig. 6 also shows electricity consumption in Maryland, which significantly exceeds generation. The difference between consumption and generation is made up by power imported from other states.

A projection of Maryland's power imports is shown in the right-hand panel of Fig. 6. This shows that the reduction in imported power under greater levels of efficiency funding will be of a magnitude similar to that of the reduction in in-state generation. In other words, efficiency funding will reduce consumption and the corresponding reduction in generation will come partly from generators in Maryland and partly from generators in other states.

Greater spending on energy efficiency in Maryland generally will reduce the RGGI CO_2 allowance price – which is in effect in all RGGI states – relative to baseline levels. This is because reduced energy consumption in Maryland translates into less regional generation, which in turn implies smaller effective demand for allowances. RGGI allowance prices, shown in Fig. 7, will be 4% lower than baseline levels if 50% of the allowance revenue is spent on efficiency and up to 9% lower than baseline levels if 100% of the allowance revenue in Maryland is spent on efficiency. Lower RGGI allowance prices will result in proportionally less RGGI allowance revenue for Maryland and the other RGGI states. The departure of allowance prices in 2025 from a path in which they increase annually at a constant discount rate results from the projected exhaustion of the allowance bank between 2020 and 2025.

3.4. *Generation capacity adequacy*

Generation capacity retirement and investment are projected by Haiku to have little dependence on efficiency spending. Coal and nuclear capacities in Maryland are projected to remain unchanged over the modeling horizon regardless of funding for efficiency programs. Natural gas capacity is projected to increase, with that increase delayed until the early 2020s, and this too is projected to be unaffected by efficiency funding. The operating profits of the generators are also not meaningfully affected by efficiency spending, with the exception of coal generators, whose profits are projected to fall in time as RGGI compliance becomes increasingly more expensive.

If the peak reductions projected by the Haiku analysis are realized, payments to power generators through the PJM RPM (capacity) mechanism by central Maryland consumers could potentially be decreased by several tens of millions of dollars annually. Whether this actually would occur depends on the amount of capacity and import capability relative to Maryland capacity needs, because of the RPM's use of a nonlinear demand curve to determine the price of capacity (Hobbs et al., 2007).

3.5. *Maryland economy*

Overall, the 100% efficiency spending scenario is estimated to have the greatest positive impact on gross state product, employment, and wages. Compared with minimum (25%) efficiency spending, the 100% efficiency scenario boosts gross state product (GSP) by $150 million in 2010 and more than $500 million in 2020. This can be compared with the incremental expenditure of RGGI funds on efficiency of $64 million and $125 million, respectively, in those years, as shown in the left-hand panel of Fig. 2. The 50% efficiency scenario provides less than half the boost, increasing GSP by around $25 million in 2010 and over $250 million in 2020, comparable with incremental expenditures of $23 million and $44 million. Although positive, these impacts are small relative to the overall state economy, equaling about 0.1% or less of GSP in each period.

Both scenarios have a net positive impact on jobs and total wages. One hundred percent efficiency spending will create about 4300 new jobs in 2020, whereas 50% efficiency will result in 1700 more jobs than the baseline scenario. These are net gains, as the analysis accounts for the economic impact of decreased direct payments to consumers out of RGGI auction proceeds as well as the effects of expenditures on energy efficiency. While these employment gains may appear large, in the context of the Maryland's 2.5 million jobs, they are fairly small.

Committing more allowance revenue to energy efficiency spending reduces the revenue available to other state programs. However, new tax revenues generated from growth in the state economy resulting from the energy efficiency investment offset these reductions by 20–30% in 2020.

3.6. *Robustness of results to model formulation: Transmission and market power*

The effects of the 50% and 100% efficiency spending scenarios (compared with the 25% baseline) on wholesale energy costs for Maryland consumers are very similar in the analysis performed using the Haiku model and that using both the competitive and oligopolistic version JHU-OUTEC model. The JHU-OUTEC model has a more detailed representation of mid-Atlantic power transmission constraints and allows for market power in the formation of wholesale electricity prices. Thus, the assumptions concerning the transmission grid and oligopolistic behavior do not change the fundamental conclusion that under the costs assumed here for energy efficiency, consumers would benefit from an expansion of the programs.

We also examined whether more extensive energy efficiency programs could mitigate market power by examining how the difference between JHU-OUTEC oligopoly and competitive prices ("price-cost mark-up") would be affected. We found that the 50% and 100% energy efficiency scenarios do not consistently lower price-cost mark-ups compared with the base (25%) efficiency scenario. In order for such effects to occur, it is necessary for energy efficiency programs to include significant elements of "demand response" mechanisms that increase the price elasticity of demand and decrease energy use when price is high. In particular, Table 1 shows price mark-ups in response to changes in the scale of Maryland's energy efficiency program. In every case, the values are close to 1 – the value that indicates no change in mark-up – and the direction of the deviation from 1 is inconsistent, suggesting that it is not possible to predict even a small change in a particular direction. The similar results obtained in the two models build confidence in the calibrated, aggregate results obtained by the Haiku model.

Table 1
Impact of expanding energy efficiency spending Maryland oligopolistic price mark-ups (1 = same % mark-up as the 25% case).

Expanding energy efficiency cases from 25% to:	2010	2015	2020	2025
50% of RGGI Revenues	1.04	1.06	0.99	1.02
100% of RGGI Revenues	0.90	0.98	1.08	1.01

An ongoing issue in Maryland is its dependency on imports when significant new transmission capacity has not been built in decades. The modeling effort reflected an assumption that two out of three of the proposed new high voltage lines between Maryland and neighboring states would be built. However, given that no transmission projects of this magnitude have been successfully completed in this region within the last 20 years and even much smaller projects have encountered significant opposition and delay. So realistic scenarios are possible in which only one or even none of the lines are completed.

It has been hypothesized that the benefits of the efficiency programs to Marylanders might significantly increase if transmission capacity is scarcer than anticipated, because the reduced consumption could substitute for imports. Therefore, as a sensitivity analysis, we considered the benefits of the 100% program funding if instead none of the proposed lines is built by 2015 rather than two. If these lines are not built, import capacity to the state is reduced by about one-third.

However, as calculated by JHU-OUTEC, the effects of funding level are not appreciably changed in that case, contrary to the hypothesis. In particular, going from 25% to 100% energy efficiency programs saves consumers about the same amount under the smaller and larger import capacities. There are about 15% fewer benefits if the two lines are not built—$118 M/yr savings in that case vs. $135 M/yr savings with the lines. In all cases, consumers appear to benefit significantly from expanding the energy efficiency programs, while Maryland generator net revenue decreases. Thus, the conclusions of this study appear robust relative to whether or not the anticipated reinforcements of Maryland's transmission links with neighboring states materialize.

The reason why the amount of import capacity does not appreciably alter our conclusions is that imports and generation are not greatly changed by the decrease in transmission capacity. In particular, decreasing transmission capacity by one-third only decreases energy imports by 0.7% of the load (30.5% of load vs. 31.2% of load) in 2015. The only discernable effects of the lower transmission on dispatch are an increase in Maryland natural gas generation by an amount approximately equal to the decreased imports, and a slight decrease in coal-fired generation equal to the decrease in Maryland energy demand. The decrease loads result from the 3.5% higher bulk power price (39.1 $/MWh without the transmission additions vs. 37.7 $/MWh with the additions).

4. Conclusions

This paper shows that larger investments of Maryland's portion of RGGI CO_2 allowance revenue in electricity end-use efficiency improvements would result in significant reductions in electricity demand in Maryland and a commensurate reduction in electricity bills faced by Maryland consumers. Because Maryland's electricity market is embedded within the larger PJM electricity market, the effects of demand reductions in Maryland will be felt beyond the state line and the changes in other states will in turn partly offset the effects within Maryland. Overall, the gross state product of the Maryland economy will grow by a small amount, with a net increase in jobs and wages.

Actual design and implementation of efficiency programs are subject to ongoing debate in the state. A key to success of these programs will be the degree to which program funding can be made certain and stable from year to year, despite potential allowance price and RGGI revenue fluctuations in the market. The higher will be the certainty and stability, the higher will be participation in efficiency programs and the larger consistentcy of our model assumptions with long-term behavior.

The Maryland Department of the Environment and the State of Maryland are interested in shrinking the state's carbon footprint and lowering overall greenhouse gas emissions while stimulating economic activity and improvements in the quality of life of Maryland citizens. RGGI addresses CO_2 emissions from electricity generators with a capacity of at least 25 MW. Other targets for reductions of greenhouse gas emissions could include industrial generation of electricity, natural gas combustion for purposes other than electricity generation (e.g., home heating), and the transportation sector. To date, no comprehensive assessment exists of such opportunities for reductions outside the RGGI targets. Such an assessment would include analysis of the implications for energy markets, their effects on consumers and associated business enterprises, as well as overall economic, social, and environmental dynamics.

Acknowledgements

The authors wish to thank the Maryland Department of the Environment for funding. Paul, Palmer, and Myers also wish to acknowledge partial support from US EPA Science to Achieve Results (STAR) Grant RD83183601 and the funders of the RFF Electricity and Environment Program, including a special grant from Exelon for work on Energy Efficiency.

References

Chen, Y., Hobbs, B.F., 2005. An oligopolistic power market model with tradable NO_x permits. IEEE Transactions on Power Systems 20 (1), 119–129.

Hobbs, B.F., Helman, U., 2004. Complementarity-based equilibrium modeling for electric power markets.. In: Bunn, D. (Ed.), Modeling Prices in Competitive Electricity Markets.. J. Wiley Series in Financial Economics, London.

Hobbs, B.F., Hu, M.C., Inon, J., Bhavaraju, M., Stoft, S., 2007. A dynamic analysis of a demand curve-based capacity market proposal: the PJM reliability pricing model. IEEE Transactions on Power Systems 22 (1), 3–11.

Houthakker, H.S., Taylor, Lester D., 1970. Consumer Demand in the United States: Analyses and Projections.. Harvard University Press, Cambridge, Massachusetts.

Maryland Energy Administration, 2008. Maryland Strategic Electricity Plan. Maryland Energy Administration (MEA), Annapolis, MD. Available online: 〈http://energy.maryland.gov/about/reports/documents/MEASTRATEGICELEC TRICITYPLAN.pdf〉.

Maryland General Assembly, 2008. Fiscal and Policy Note: EmPOWER Maryland Energy Efficiency Act of 2008. Available online 〈http://mlis.state.md.us/2008rs/fnotes/bil_0004/hb0374.pdf〉.

Minnesota IMPLAN Group, Inc. (MIG, Inc.), 2006. Viewed at 〈http://www.implan.com〉.

Paul, Anthony, Dallas Burtraw, and Karen Palmer. 2009a. Haiku documentation: RFF's Electricity Market Model Version 2.0. RFF Report, January. 〈http://www.rff.org/RFF/Documents/RFF-Rpt-Haiku.v2.0.pdf〉.

Paul, Anthony, Erica Myers, Karen Palmer. 2009b. A partial adjustment model of U.S. electricity demand by region, season, and sector. RFF Discussion Paper 08-50, April 〈http://www.rff.org/Publications/Pages/PublicationDetails.aspx?PublicationID=20773〉.

PJM, 2001. PJM Hourly Load. Available online: 〈ftp://ftp.pjm.com/pub/market_system_data/system/hourly_prelim_loads/daily〉.

PowerWorld, 2003. Available online: 〈www.powerworld.com/downloads.html〉.

Regional Greenhouse Gas Initiative, 2005. Memorandum of understanding. Regional Greenhouse Gas Initiative (RGGI), available online: 〈http://rggi.org/docs/mou_12_20_05.pdf〉.

Regional Greenhouse Gas Initiative, 2007. Overview of RGGI CO_2 Budget Trading Program (p4). Regional Greenhouse Gas Initiative (RGGI), available online: 〈http://rggi.org/docs/program_summary_10_07.pdf〉.

Regional Greenhouse Gas Initiative, 2008. Final report of the RGGI emissions leakage multi-state staff working group to the RGGI agency heads (March). Regional Greenhouse Gas Initiative (RGGI), available on-line: 〈http://www.rggi.org/docs/20080331leakage.pdf〉.

Ruth, M., Gabriel, S., Palmer, K., Burtraw, D., Paul, A, Chen, Y., Hobbs, B., Irani, D., Michael, J., Ross, K., Conklin, R., Miller, J., 2008. Economic and energy impacts from participation in the regional greenhouse gas initiative: a case study of the state of Maryland. Energy Policy 36, 2279–2289.

Schweppe, F.C., Caramanis, M.C., Tabors, R.D., Bohn, R.E., 1988. Spot Pricing of Electricity. Kluwer Academic Publishers.

Ventosa, M., Baíllo, Á., Ramos, A., Rivier, M., 2005. Electricity market modeling trends. Energy Policy 33 (7), 897–913.

Yao, J., Adler, I., Oren, S., 2008. Modeling and computing two-settlement oligopolistic equilibrium in congested electricity networks. Operations Research 56 (1), 34–47.