Title

Renewable Energy Adoption and its Impact on U.S. Energy Systems

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Renewable Energy Adoption and its Impact on U.S. Energy Systems

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Abstract

In this paper, I investigate how oil price shocks and volatility affect adoption of renewable energy technologies by private businesses and households. Additionally, I analyze the changes in electric utilities' energy supplies sourced from fossil fuel-powered generators as private renewable energy adoption increases. This paper considers net energy metering program adoption as a measure of renewable energy technology uptake. I estimate two models on a panel dataset of electric utility-level data of net energy metering programs. The empirical results indicate that oil price shocks and oil price volatility reduce renewable energy adoption through net metering programs by a significant magnitude. The findings also show that greater customer net metering subscription significantly reduces utilities' reliance on fossil fuels for their retail electricity supplies. Coal and natural gas generator usage is most reduced, while oil-fired generator reliance is affected fractionally. Recommendations for improving renewable energy policies and considerations for further reducing utilities' reliance on fossil fuels are made based off these findings.

Introduction

The United States is in the process of a huge energy transition from non-renewable energy (NRE) to sustainably-sourced power. The dominance of fossil fuels in energy markets will diminish in the near future, as concerns for the environment grow and viable supplies of crude oil, gas, and coal dwindle. However, encouraging the adoption of renewable energy (RE) such as solar or wind in the American energy market is a huge effort to accomplish. Replacing the entire nonrenewable-based infrastructure of the U.S. energy system will be no easy task, but steps must be taken to drive this transition away from carbon-fueled energy.

According to the U.S. Energy Information Agency, renewable sourced power has grown threefold in the past two decades. As of 2019, renewable power accounts of 11.4% of energy consumption, and this proportion is expected to grow in the coming decades (“Renewable Energy Explained”). As alternative energy’s role in the energy system grows, drastic changes in the structure of the electricity market are likely to take place.

Traditional electric utility companies have already increased their investments into renewable power generation by constructing large scale solar panel or wind turbine farms. As a result, the overall supply of electricity powered by alternative energy technologies has grown vastly, and reliance on fossil fuels for electricity production has begun to shrink (“Demystifying U.S. Electricity Markets”).

This shift to sustainable energy has not only been driven by utility companies’ adoption of RE technologies. Compared to non-renewable power, renewable energy can be produced through smaller scale technologies that even non-utilities, such as households and businesses, can utilize. This has therefore led to private-end investment into renewable energy technologies like rooftop solar panels or small-scale wind turbines. In the past, energy production has been limited to utility companies due to the capital-intensive production of energy from non-renewable sources like coal, oil, and natural gas. With this outgrowth of renewable energy technologies, households and businesses can rely less on fossil fuels and utility-produced power by adopting RE technologies. This development likely has huge effects for the energy grid in the near future.

There are two implications from this growing movement of consumer-end adoption of renewable energy. First, for the consumers that consider adopting RE technologies, the risk of RE investment falls upon them and not their utility company. In the past, utility companies were the sole motivators of the NRE-to-RE transition, where each utility would consider the costs and benefits of installed renewable generators and their ability to make a return on these investments. Now that renewable energy adoption is available to households and non-utility businesses, the risks and returns of a RE investment becomes a calculation for the non-utility agents that consider adopting these technologies. As a result, private RE investment and adoption can become liable to certain economic shocks that traditionally slow down investment-making in large fixed projects like rooftop solar panels or wind turbines. These include oil price shocks (OPS) and oil price uncertainty (OPV). Extensive research has shown investment decisions are reduced in response to OPS and OPV, so in this study I evaluate whether this result is consistent regarding household and business RE investments or if private-end adoption has attractive mechanisms that facilitate uptake independent of oil market signals.

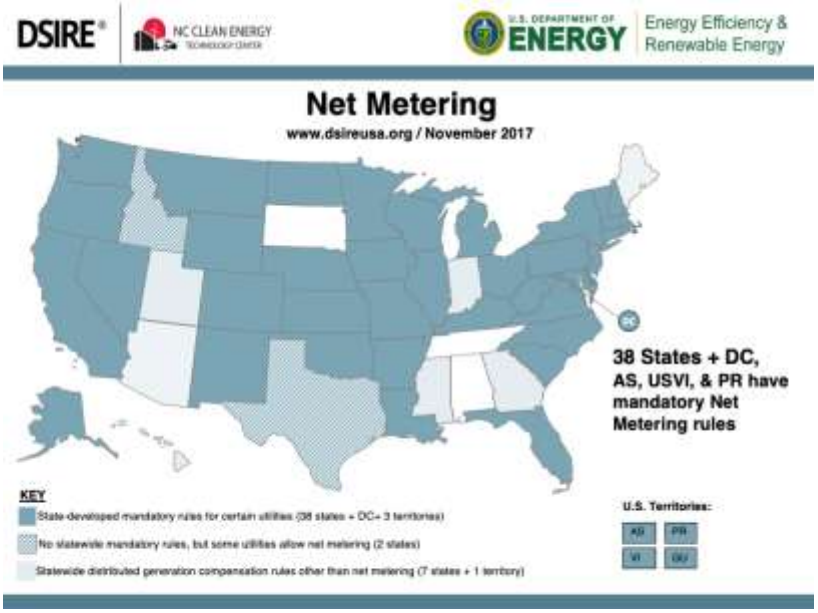
The second implication for non-utility adoption of RE is the shifted energy market dynamics. In a given utility company jurisdiction, when more consumers are producing and relying on self-produced renewable energy, utility companies face a decreased demand for utility-produced energy. Combined with a growing supply of renewable-sourced power, newer electricity market equilibria can be established that reduce the reliance on fossil fuels in retail electricity production. Beyond assessing the effects of OPS and OPV on renewable energy adoption, I analyze the responses of utility companies to this newer consumer-end investment in RE. The analysis shows how consumer-end RE adoption will affect energy markets and determines whether consumer adoption is aiding in the driving out of non-renewable fuel usage in electricity production.

The rest of the paper is organized as follows. First, I describe one of the significant policies that is driving consumer-end adoption of renewable energy: net energy metering. Then, I layout the limits of consumer-end RE adoption due to traditional investment-limiting effects of oil market price levels and volatility. Next, I point out some of the expected responses of utility companies to RE adoption and the subsequent reduction in utility-produced energy demand. I highlight some of the academic literature that regards both subjects, and then I define empirical models to test the response of RE adoption to oil market signals and the changes in energy production as a result of greater private RE investment. I also document my data collection and processing to estimate these models. I finish the paper with presenting empirical analysis results and discussing the findings.

Consumer-End RE Adoption: Net Energy Metering

One program that has facilitated non-utility adoption of renewable energy technology adoption has been net energy metering (NEM) programs. As a way to incentivize adoption and improve energy efficiency, state governments created these NEM policies that allow energy consumers to install RE technologies, produce and consume their own electricity, and sell back excess energy to utility companies at a compensation rate (*Energy and Environment Guide to Action* p.64-65). Under NEM, electricity users secure RE technologies like rooftop solar panels or small-scale wind turbines, apply for NEM subscription with their utility company, and install the technologies. After that, NEM adopters can benefit from self-produced energy and profit off the sell-back mechanism. As of 2018, NEM programs are mandatory in 38 states, though compensation rules, approved nameplate capacities, and grid capacity limits vary across regions ("Net Metering State Policies"). The regional spread of available NEM policies can be seen in Figure 1, which is provided by the U.S. Department of Energy.

Figure 1



Net metering programs have greatly aided in the transition to renewable energy by allowing adoption of RE technologies by households and commercial businesses. NEM's popularity has grown immensely in the past decade. From 2011 to 2019, the proportion NEM subscribers had grown to about 1% of total energy customers in the United States (see Figure 2 below). Monthly RE instillations geared for NEM programs have also seen huge outgrowth in the past decade. There are now over 10000 RE technology instillations for these programs each month across the United States (refer to Figure 3).

NEM adoption provides several benefits across the energy system. According to the Environmental Protection Agency’s *Energy and Environment Guide to Action*, net metering mitigates sudden surges in energy demand for utility-generated power, reduces the environmental impact of electricity production, and increases energy savings for willing RE adopting households and businesses (p.65). As a result, net metering programs can have huge impacts on the structure and operations of the energy system.

The compensation structure of NEM programs is also a huge benefit that can help incentivize RE adoption. It allows energy consumer to consider their energy needs and create an expectation of payoffs for adopting RE technologies. If they consider their average energy needs and the expected production capacity of their installed rooftop solar or wind turbine units, they can anticipate a level of energy savings or expected profits from selling any excess energy back to their electricity grid. This means NEM can provide a financing mechanism for RE technologies; adopters can pay off loans or lease payments, or they can remit instillation costs by utilizing the sell-back proceeds.

Figure 2

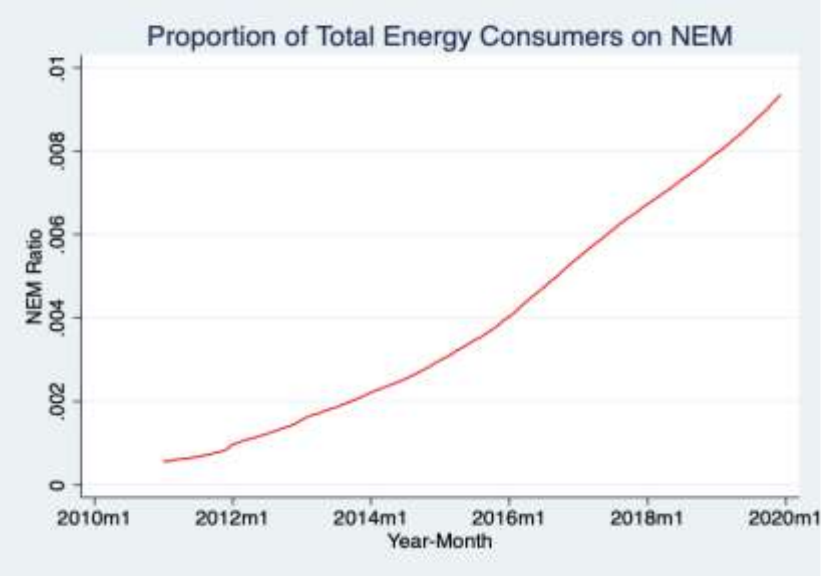
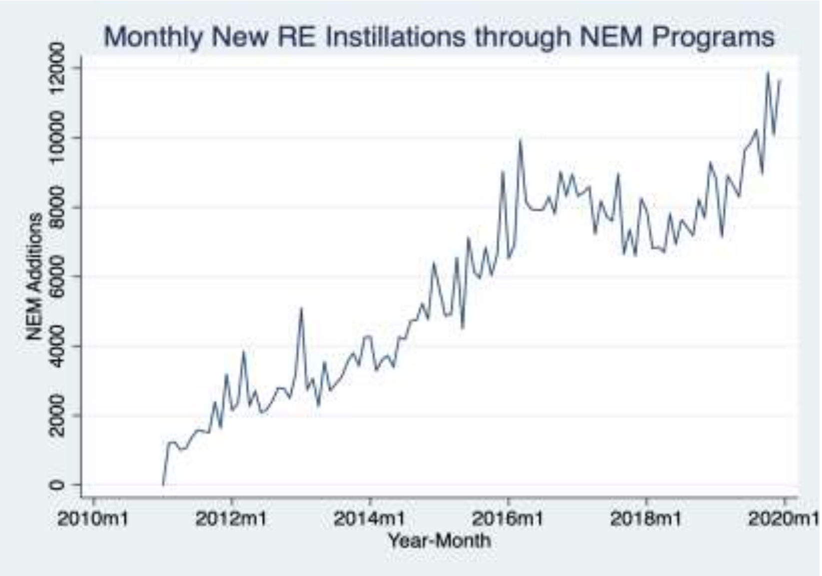


Figure 3



Oil Markets and Investment: Is NEM Adoption Affected?

Now despite the benefits and growing popularity of NEM, the nature of its adoption by private-end electricity consumers is limited by certain factors. As a consumer-decided program, the decision to opt into NEM programs and install RE technologies is liable to considerations of anticipated project payoffs. This is a similar consideration framework that companies and households use when deliberating on investments or purchases of durable goods. However, this means that economic factors that warp investment perceptions and expected returns can influence RE adoption.

There has been considerable literature on factors that limit private investment or residential purchases by households and businesses. Some of the limiting factors are oil markets signals, such as price shocks or price volatility. Several scholars have found a link between reduced investment and durable goods purchases in response to OPS and OPV. The literature review section of this paper documents these studies, but across all of them a significant negative influence on investment-making due to oil market signals. This fact emerges mostly from petroleum's historical integration into U.S. businesses production, and the overall lack of diversification from oil-based technologies into alternative sources for both production, energy consumption, and other operations (Henriques and Sadorsky, 2011).

Since nonrenewable fuels such as oil have a distinct impact on the decision making of firms and households, it makes sense that private, non-utility investments into renewable energy could have a relationship with fossil fuels markets. The U.S.'s historical reliance on oil has ingratiated petrol's importance on business production and investment decision-making across the economy. According to Elder and Serletis (2010), oil price shocks or volatility reduce expected payoffs of investments, so households and businesses reduce their fixed goods and investment purchases. Energy customers are already very sensitive to expected payoffs and upfront costs of energy efficiency projects like RE, and experienced market uncertainty exacerbates aversion to energy-related investments (Ameli and Brandt, 2014). On top of this, RE project costs are not very competitive, and returns are especially uncertain (Shah, Hiles, and Marley, 2018).

However, net energy metering programs could provide a structure that prevents or mitigates private RE adoption's exposure to oil prices by reducing payoff uncertainty and adoption costs. NEM allows consumer production and consumption of renewable-sourced power, which is limitless. At the same time, NEM programs have established compensation structures for users that sell their excess energy back to the grid. This allows energy efficient NEM subscribers to utilize the payment mechanism to finance or profit off their RE technology instillations as long as they consider their own energy needs and the overall capacity of their technologies. Taken together, NEM can reduce uncertainty about returns on RE investments by providing a transparent compensation mechanism. This means that the economic uncertainty added from OPV and OPS could be mitigated for RE investments by the transparency and set payoff structure of NEM programs.

Utilities' Response to Consumer RE Adoption

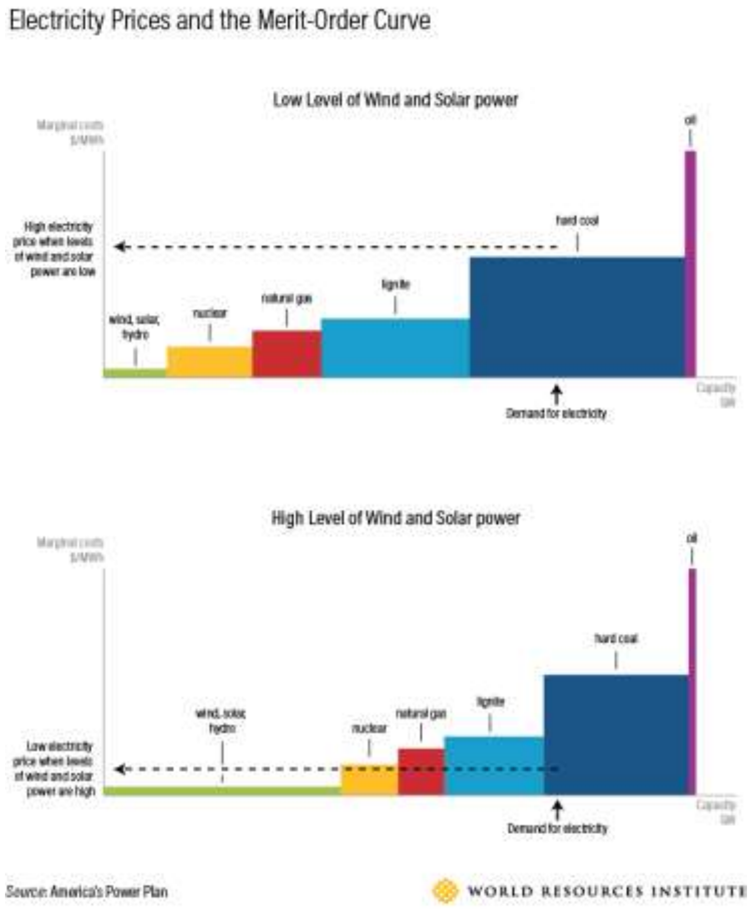
Since consumer-end energy production and reliance through RE technologies and net metering are relatively new development in electricity markets, great changes in utility company operations can be expected. RE adoption by households and businesses lead to a reduction in demand for utility-produced electricity, since these RE users are relying on their own produced power. Additionally, net energy metering allows these households and businesses to act as prosumers of electricity by selling excess power back to their energy grid. This leads to an increase in RE-sourced power in the supply of energy, coupled with the mentioned reduction in demand (*Energy and Environment Guide to Action* p.64-65). This situation suggests that RE adoption alters the supply-demand dynamics of the energy market, and this could have even greater implications on the usage of fossil fuels to produce and supply retail electricity.

Already, researchers of energy grids have noted a so-called Merit Order Curve (MOC) in the supply of electricity. The MOC framework indicates that the supply of electricity is ordered by the marginal cost of electricity produced and sourced from different generator types. Utility companies typically have multiple generator types to supply electricity to their regional grid. These generators can be sourced by various fossil fuels, such as natural gas, oil, or coal. When meeting the demand for electricity, the utilities will supply electricity from cheaper fuel type generators up to capacity. If supply from one generator type doesn't clear the market, other generator types with higher marginal costs will be utilized to cover the remaining needed supply ("Demystifying U.S. Electricity Markets"). They will also consider wholesale fuel or energy prices when shifting production between different generator types. For example, if natural gas prices go up, the supplies of non-gas-fueled power such as coal or oil increase ("Today in Energy")

Controlling for wholesale fuel price factors, typically heavier carbon-based fuels have higher marginal costs for energy production such as coal or oil, so they are ordered farther out on the merit order supply curve of energy. Especially due to its cost and environmental factors, oil is used the least in energy production, and is typically reserved for meeting sudden short-run spikes in electricity demand ("Today in Energy").

An illustration of a hypothetical, market-clearing MOC from the World Resources Institute is shown in Figure 4 below.

Figure 4



Source: America's Power Plan

This MOC framework of the energy supply has huge implications and possibilities for the renewable energy transition. With electricity supplied by sources in ascending order of marginal costs, induced supply and demand shifts in the energy markets can help edge out fossil fuels usage in energy production. Renewable energy is known to have a near-zero marginal cost for production, so as utilities invest more in RE and gain a greater supply of alternative power, the Merit Order Curve framework implies that the supply curve for energy will shift outwards, prices will lowers, and reliance on fossil fuel-sourced electricity is driven out (Cludius, et al, 2014). But, RE adoption from the utility end is not the necessary condition for this driving out of fossil fuels to occur. Net energy metering programs and consumer-end adoption of RE technologies can shift demand backwards as a smaller proportion of utility region residents rely on their utility's produced power. This demand shift coupled with greater RE-sourced power in the energy supply could theoretically drive out the reliance on carbon-heavy fossil fuels in electricity production.

These components imply that RE's adoption by consumers and growing supply penetration can have huge impacts on the nature of energy production by utility companies. I investigate how fossil fuel reliance changes as NEM adoption grows and demand for utility power reduces subsequently. These findings can have a huge impact on our understanding of the dynamics that are driving the energy transition process and increases the role of alternative energy in the United States' electricity systems.

Literature Review

Oil Markets, Investment, and Renewable Energy Adoption

There is fairly substantial literature on the subject of investment responses to oil price shocks or oil price volatility, which can then be extended to the subject of adoption of renewable energy technologies by private households and businesses.

Elder and Serletis (2010) find that oil prices and volatility negatively affect investment and durable goods consumptions by firms and households. They explain some of the studied frameworks for why this occurs. For one, oil price shocks reduce real value of savings and financial capital. This then brings down real value of resources that can be put into new projects. Additionally, price shocks create uncertainty about investment returns and expected payoffs since consumers also realize a reduction in real savings from OPS or OPV. Their findings suggest that fixed investments and durable goods, which include residential or commercial site additions such as RE technologies, are most affected by oil price shocks or uncertainty.

Henriques and Sadorsky (2011) discuss a similar topic of investment response and discover consistent findings with the above study. They explain that for commercial firms, the value to postpone or suspend investments increases as oil price volatility increases. Irreversible investments, such as renewable energy technologies, often have uncertain future payoffs, and returns could be liable to future market conditions or uncertainty. Henriques and Sadorsky (2011) point out that various aspects of the U.S. economy remain undiversified from oil within the value chains of production. Nearly 98% of all consumption goods involve oil inputs somewhere within their production. Their findings demonstrate oil prices and uncertainty reduce investment significantly. Realized volatility appears to have a significant impact on investment decisions.

Both the above studies focus on aggregate or firm investment. Their studies do not look specifically as RE investment and what factors reduce alternative energy uptake. Ameli and Brandt (2014) fill this gap in understanding RE adoption and the factors affecting it. They survey various studies over the past 30 years that examine factors that have inhibited the outgrowth of renewable energy adoption. For one, energy consumers (i.e. businesses and households), tend to attach considerations of initial investment costs to their decision-making when considering energy efficiency or renewable energy products. They are more sensitive to initial project costs than they are to anticipated savings or payoffs from RE adoption. Much of this situation emerges from implicit beliefs about future market volatility. Typically, energy consumers that are considering energy efficiency or renewable energy projects price in a certain level of uncertainty into their payoffs for the project. They are very sensitive and averse to uncertain returns on their investments, and previously realized energy market volatility, such as from oil prices, seems to add to aversion to these projects. Due to this, the studies recounted in this paper find underinvestment in business or household-end renewable energy technologies due to the perceived uncertainty and high costs of RE projects.

Ameli and Brandt (2014) also point out various adoption constraints for prospective RE users. Credit constraints make RE instillations unattractive for many electricity consumers. Even for credit-providers, RE projects are risky with uncertain future payoffs. This has contributed to the larger costs of RE investments and difficult financing options. Indeed, the authors note that only 6.5% of RE installers utilize formal loans. With limited financing options available, left-out groups such as low-income households and low-profit businesses are far excluded from the options to invest in renewable energy. Ameli and Brandt (2014) therefore argue for improved financing policies that reduce perceived costs and provide attractive financing options.

Merit Order Curve and Energy Markets

The subject of Merit Order supply curves of electricity is studied moderately and mostly in the context of European markets. The MOC framework is based off standard supply curve fundamentals, so the idea of RE market penetration affecting the portfolio of fossil fuel usage in energy production is easily extendible to outside energy markets across the developed world. Cludius, et al (2014) is one example study into Merit Order Curve effects of renewable energy adoption, in which the authors study the German energy market. They explain that electricity is competitively supplied, and energy providers price their energy at prices based of marginal costs of fuel usage. This leads to an ordering of energy supplied by different fuel sources according to marginal costs. They explain that renewable energy generators have low marginal costs and are ordered farther left on the supply curve. More expensive, and typically more environmentally dangerous or carbon-heavy, fuels like natural gas, coal, or oil are order farther out on the curve. The penetration of greater RE into the supply curve drives out total electricity supplied by NRE, since RE entrance shifts the supply curve and lower prices below these dirtier fuels' marginal costs. Their study does not consider possible demand changes and how those affect the supply of electricity by fuel types, however.

Roldan-Fernandez, et al (2016) therefore build off this Merit Order Curve research by explaining that the combination of RE adoption shifting energy market demand with renewable energy supply growth helps drive out usage in dirtier NRE fuel types and improves overall energy efficiency.

Paper Contributions

Inspired by the studies on investment response to oil markets, I build on the understandings of RE investment in response to OPS and OPV by investigating private-end adoption of RE technologies through net metering programs. Net energy metering programs offer energy consumers the ability to produce renewable power, and NEM provides a set financing and payment structure that could improve considerations towards and anticipated returns from RE investment. I seek to conclude whether NEM programs are attractively established to incentivize easy RE adoption, or if they still suffer from consumer-end discounting, risk aversion, and uncertainty of future payoffs as discussed in Ameli and Brandt (2014).

I then examine how consumer-end RE adoptions reduce the NRE usage of utility companies. Based off the MOC framework from the studies mentioned earlier, I attempt to evaluate whether a significant shift in energy allocation by fuel types is occurring in U.S. electricity markets as demand is reduced through NEM adoption. Additionally, I identify which fossil fuels are most reduced in utility reliance by wider-spread NEM adoption.

Empirical Strategies

Model 1: Renewable Energy Adoption and Oil Price Shocks and Volatility

In my empirical analysis, I first model the responsiveness of renewable energy adoption to oil price shocks and volatility. I look at the changes in the number of new RE instillations through net energy metering programs following increased levels or volatility of oil prices. I therefore specify the following model:

$$\begin{aligned}
&log(New\_NEM\_Installations)_{i,t} = \boldsymbol{\beta}_1 log(Utility\_Region\_Size)_{i,t-1} \\
&\quad + \boldsymbol{\beta}_2 Energy\_Use\_Per\_Customer_{i,t-1} + \boldsymbol{\beta}_3 Avg\_NEM\_Capacity_{i,t-1} + \\
&\quad \Sigma^{4}_{j=1} (\boldsymbol{\beta}_{3+j} Oil\_Price_{t-3(j)} + \boldsymbol{\beta}_{7+j} Oil\_Volatility_{t-3(j)}) + a_i + d_t + e_{i,t}
\end{aligned}$$

My dependent variable is the natural logarithm of newly installed RE units through a utility company's NEM program. This measure captures the changes in RE adoption by private households and businesses, since newer net metering units would only be installed upon decision-making by the net metering applicant.

The instillation of RE technologies through NEM by energy consumers is affected by a variety of components. Greater energy grid size makes consumer-end energy production an attractive option from the utilities' perspectives, since larger regions have higher energy demands which leads to greater costs and grid management for the electric companies. Net metering programs reduce the strain on the local energy grids since less customers are demanding power from their utility's production, so RE adoption through NEM could actually be attractive for larger energy grids. I control for this by including the size of the given utility region, measured by the natural logarithm of total utility customer count. Additionally, per capita energy usage is another factor that affects instillation RE technologies through net metering. Renewable technologies used for net metering typically have lower generational capacity and are better suited for reducing reliance on utilities' produced power for less demanding energy customers. Therefore, it is less attractive to pay to install RE technologies and opt into NEM if energy consumers realize relatively smaller reductions in utility reliance or smaller increases in savings due to greater energy needs. Likewise, if the average generational capacity for a prospective NEM unit for a region is small, the incentives of RE adoption are also reduced. I therefore include the two variables *Energy_Use_Per_Customer* and *Avg_NEM_Capacity* to capture relative attractiveness of NEM subscription for the energy consumer's perspective.

The coefficients of most interest for this model are on the quarterly lagged values of oil prices and volatility. I include a full year of quarterly lags of both covariates. There are two possible implications for the resulting signs on the oil price shocks and oil price volatility variables. If either OPS or OPV negatively affects RE adoption in net metering programs, this would mean that oil markets influence RE investment in the same way as any other fixed investment, as in line with previous studies laid out earlier in this paper. NEM programs would not therefore mitigate the uncertainty of or provide attractive financing for RE adoption in the presence of oil price shocks or volatility. Alternatively, if RE adoption is unaffected by oil market shocks or volatility, then net energy metering programs are meaningful mechanisms to boost RE adoption. If no effect, then NEM policies limit uncertainties of payoffs for renewable energy investments and hold up adoption even in the presence of typical investment-limiting shocks such as oil price movements or volatility.

Model 2: Renewable Energy Adoption and Utilities' Fossil Fuel Reliance

For the next model, I analyze how utilities' reliance on fossil fuel electricity generators changes as a greater portion of regional customers adopt renewable technologies through NEM. I specify the following regression model:

$$NR\_Fuel\_Reliance_{i,t} = \boldsymbol{\beta}_1 log(Utility\_Energy\_Produced)_{i,t-1} + \boldsymbol{\beta}_2\, Electricity\_Price_{i,t-1} + \boldsymbol{\beta}_3 NatGas\_Price_{i,t-1} + \boldsymbol{\beta}_4 Oil\_Price_{i,t-1} + \boldsymbol{\beta}_5 NEM\_Ratio_{i,t-1} + a_i + d_t + e_{i,t}$$

I run this model for three main types of non-renewable fuels used in electricity generation: natural gas, coal, and oil. I observe how the proportion of total monthly energy produced by each fuel type changes in response to greater customer subscription to NEM programs with each utility company. This model aims to measure how the composition of fossil-fuel sourced energy in utilities' energy supplies are affected by consumer-end RE adoption. NEM subscription by electricity consumers both reduces regional demand for utility-produced power and can increases the supply of renewable-sourced energy as customers sell their excess electricity back to the grid. If NEM adoption has a significant impact on energy systems, we would notice a significant reduction in fossil fuel reliance in line with the framework of a Merit Order Curve for electricity supplies.

To control for scaling differences across utilities, I add the logarithm of total energy production to the model. I then include price covariates for natural gas, oil, and electricity. These prices impact the fuel use allocation decisions of utility companies, especially increases in natural gas prices which likely affect usage in other energy generator types like coal and oil. Changes in these input prices or expected retail-end prices likely affect utilities' generation choices to provide the most cost-effective and profit-maximizing supply of energy. For example, a change in wholesale natural gas prices raises the cost of natural gas-source energy generation, so other fuel type generators become more attractive like coal or oil.

The variable of interest for this model is the *NEM_Ratio* covariate, which measures the ratio of total NEM subscribers to total energy customers in a given utility region. Greater NEM adoption in a region takes away strain on the energy grid, since more energy consumers are self-producing and self-consuming electricity produced by their installed RE units. Additionally, some NEM users are selling excess energy back to their utility's grid, so this is increasing the supply of low-cost renewable energy. Under the supply-demand framework, this would mean that greater NEM adoption shifts a given utility region's electricity demand curve left, as a smaller portion of consumers rely on grid-supplied power. On top of this, added renewable energy supply from RE-producing NEM users shift the supply curve of energy out right.

I make no attempt to determine net price changes or identify shifted equilibrium points from this changing market dynamics due NEM adoption. I only attempt to identify how reduced utility power demand from NEM subscription affects the overall supply of fossil fuel-powered energy. By looking at the proportions of energy provided by different fuel types, we can identify what fuel types are most reduced in usage as these market shifts occur with RE adoption through net metering.

Data

Sources

The data to run the above models are collected from the Department of Energy's Energy Information Agency (EIA). This agency collects utility-level data on energy production, prices, customer counts, and net metering adoption for a representative sample of utilities across the United States. They provide two monthly datasets relevant to this study.

First, the EIA's Form 861M contains monthly customer and net metering data for a sample of about 300 utility companies. This form also provides revenue and sales variables that allow me to proxy for average monthly electricity prices. This data goes back only to 2011 and is complete up to 2019. Therefore, I set the time period for this analysis from January 2011 to December 2019.

Next, the EIA's Form 923 collects monthly generator-level data on production of electricity for hundreds of utilities across states. This dataset breaks down production to the plant level and it provides fuel usage information for each one. This allows me to aggregate electricity production by fuel type and construct measures of energy reliance on non-renewable fuels, which include oil, natural gas, and coal.

After collecting and aggregating the individual datasets, I drop utility companies that do not have complete and continuous data reporting for at least 5 years through December 2019. From the net metering and customer dataset from the Form 861M, I obtain 227 distinct utility companies from across the United States. I then merge these 227 utilities to the production-level dataset from the Form 923 and obtain a successful match of 89 of the 227 companies.

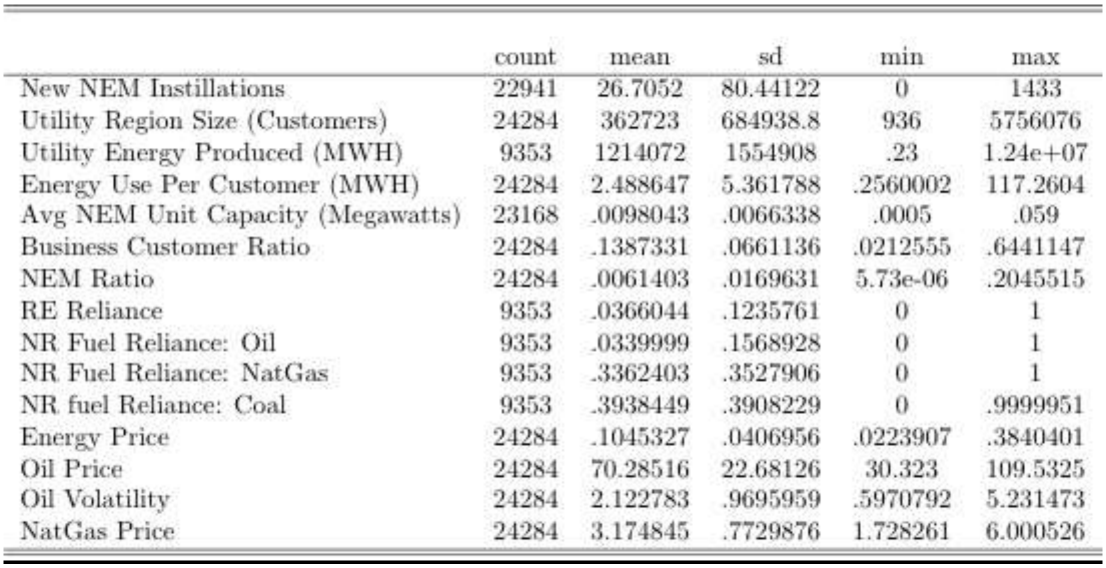
Finally, from the EIA's data portal, I obtain daily oil and natural gas prices for my sample period. These prices come from the Western Texas Intermediate crude oil spot price and the Henry Hub natural gas spot price. I average prices by month and construct a volatility measure defined as the standard deviation of daily spot prices for a given month. I merge the price and volatility measures for both fuels to my merged dataset of utility companies.

I provide a table of variable definitions for relevant measures and covariates below. I also include a summary of statistics for each of the defined variables.

Variable Descriptions Table

NAME	DESCRIPTION
New_NEM_Instillations	Number of newly-added net metering units, either solar or wind-based
Utility_Region_Size	Total number of regional energy consumers
Utility_Energy_Produced	Total electricity produced for customer-end consumption from all fuel type generators
Energy_Use_Per_Customer	Average electricity consumption in megawatt hours per customer
Avg_NEM_Capacity	Average nameplate capacity for net energy metering units (solar or wind) for a given utility region
NEM_Ratio	Proportion of utility customers that subscribe to net metering programs
NR_Fuel_Reliance	Proportion of total energy produced from fossil fuels such as coal, natural gas, or crude oil
Oil_Price	Western Texas Intermediate (WTI) crude oil spot price
Oil_Volatility	Monthly standard deviation of daily oil prices
Electricity_Price	Average electricity price
Natural_Gas_Price	Henry Hub natural gas spot price

Summary Statistics Table



	count	mean	sd	min	max
New NEM Instillations	22941	26.7052	80.44122	0	1433
Utility Region Size (Customers)	24284	362723	684938.8	936	5756076
Utility Energy Produced (MWH)	9353	1214072	1554908	.23	1.24e+07
Energy Use Per Customer (MWH)	24284	2.488647	5.361788	.2560002	117.2604
Avg NEM Unit Capacity (Megawatts)	23168	.0098043	.0066338	.0005	.059
Business Customer Ratio	24284	.1387331	.0661136	.0212555	.6441147
NEM Ratio	24284	.0061403	.0169631	5.73e-06	.2045515
RE Reliance	9353	.0366044	.1235761	0	1
NR Fuel Reliance: Oil	9353	.0339999	.1568928	0	1
NR Fuel Reliance: NatGas	9353	.3362403	.3527906	0	1
NR fuel Reliance: Coal	9353	.3938449	.3908229	0	.9999951
Energy Price	24284	.1045327	.0406956	.0223907	.3840401
Oil Price	24284	70.28516	22.68126	30.323	109.5325
Oil Volatility	24284	2.122783	.9695959	.5970792	5.231473
NatGas Price	24284	3.174845	.7729876	1.728261	6.000526

Empirical Results

Model 1: RE Adoption Response to OPS and OPV

The results of Model 1 are presented below. For each coefficient, heteroskedastic robust standard errors are reported.

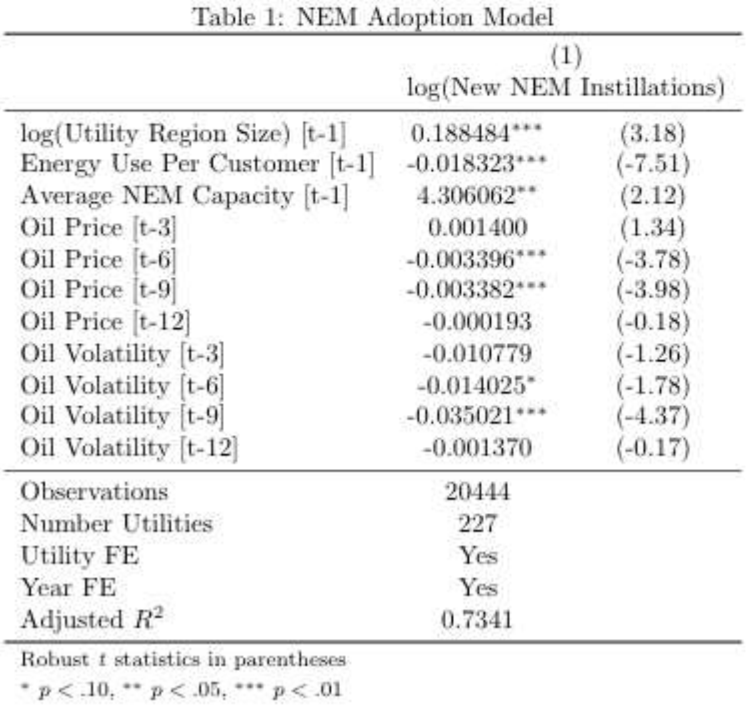


Table 1: NEM Adoption Model

	(1) log(New NEM Instillations)	
log(Utility Region Size) [t-1]	0.188484***	(3.18)
Energy Use Per Customer [t-1]	-0.018323***	(-7.51)
Average NEM Capacity [t-1]	4.306062**	(2.12)
Oil Price [t-3]	0.001400	(1.34)
Oil Price [t-6]	-0.003396***	(-3.78)
Oil Price [t-9]	-0.003382***	(-3.98)
Oil Price [t-12]	-0.000193	(-0.18)
Oil Volatility [t-3]	-0.010779	(-1.26)
Oil Volatility [t-6]	-0.014025*	(-1.78)
Oil Volatility [t-9]	-0.035021***	(-4.37)
Oil Volatility [t-12]	-0.001370	(-0.17)
Observations	20444	
Number Utilities	227	
Utility FE	Yes	
Year FE	Yes	
Adjusted R^2	0.7341	

Robust t statistics in parentheses

* $p < .10$, ** $p < .05$, *** $p < .01$

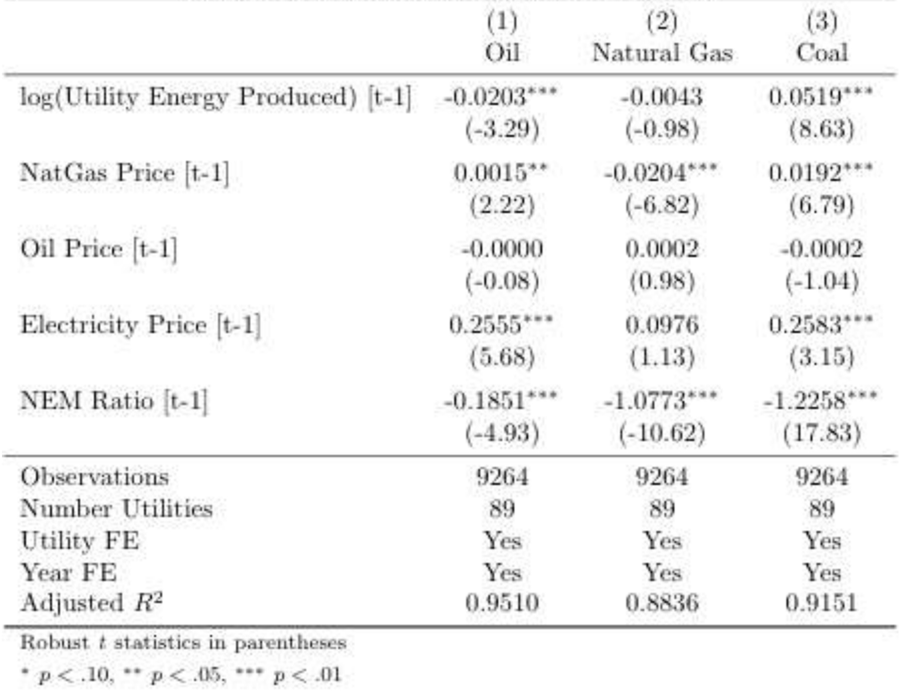
These results confirm many of the expectations from the empirical framework. Larger utility regions appear to have significantly greater rates of RE instillations through NEM. Next, regions with higher energy needs per customer have significantly lower rates of RE instillations by electricity consumers. All things equal, a region with customers that on average require one additional megawatt hour in per capita energy needs experience nearly 2% lower rates of monthly RE adoption in net metering programs. Similar to this, regions with higher capacity options for net metering units see a greater rate of adoption. Altogether, it appears that average consumer-level energy needs and generational options hold a significant influence on the rates of RE adoption by businesses and households in an electric utility jurisdiction.

Now, it appears that, with a considerable lag, consumer-level RE adoption is negatively affected by both oil price levels and volatility. Around the 6 or 9 month lags, oil prices reduce the rate of NEM subscription by close to .5% for every $1 increase in spot prices. This measures up to about a 6.5% reduction for a standard deviation increase in the pierce of oil. Similarly, at a 9 month lag, an increase in the realized volatility of oil prices by a standard deviation leads to a 3% decline in adoption. Conducting an F-test, I find that the blocks of lagged coefficients on oil prices and oil volatility are both significant beyond the 1% level.

Model 2: Renewable Energy Adoption and Utilities' Nonrenewable Fuel Reliance

Table 2 reports the findings for Model 2 on measures of reliance for each type of non-renewable fuel. Each column reports the model run on the proportion of oil, natural gas, and coal to total energy production for the utility companies in this analysis. Heteroskedastic robust standard errors are reported in the table.

Table 2: Non-Renewable Fuel Reliance Models



	(1) Oil	(2) Natural Gas	(3) Coal
log(Utility Energy Produced) [t-1]	-0.0203***	-0.0043	0.0519***
	(-3.29)	(-0.98)	(8.63)
NatGas Price [t-1]	0.0015**	-0.0204***	0.0192***
	(2.22)	(-6.82)	(6.79)
Oil Price [t-1]	-0.0000	0.0002	-0.0002
	(-0.08)	(0.98)	(-1.04)
Electricity Price [t-1]	0.2555***	0.0976	0.2583***
	(5.68)	(1.13)	(3.15)
NEM Ratio [t-1]	-0.1851***	-1.0773***	-1.2258***
	(-4.93)	(-10.62)	(17.83)
Observations	9264	9264	9264
Number Utilities	89	89	89
Utility FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Adjusted R^2	0.9510	0.8836	0.9151

Robust t statistics in parentheses

* $p < .10$, ** $p < .05$, *** $p < .01$

These results show an interesting scaling effect that influences reliance across fuel types. Utilities with greater electricity generation rely less on oil-fired power plants to produce their supply of energy. At the same time, larger utilities have greater usage of coal in their power production. No scaling effect appears with natural gas reliance, likely meaning utilities of all sizes rely on similar proportions of natural gas for electricity generation.

Wholesale fuel price signals seem to significantly alter production allocation for each generator type. A $1 increase in natural gas spot prices leads to a reduction supply of natural gas sourced electricity by 2%. At the same time, the total proportion of electricity supplied from coal and oil generators combined covers this reduction in natural gas reliance. That is, oil-fired energy reliance increases by 0.15% and coal-fired energy increases 1.9%. It appears then that in response to wholesale natural gas price changes, coal and oil generators cover the reduction in energy supply from natural gas power plants.

Finally, renewable energy usage by consumer-end NEM adoption appears to have significant negative effects on nonrenewable fuel reliance in utilities' electricity supply. Across all 3 fossil fuel types, greater NEM adoption reduces utilities' production reliance. That is, the proportion of electricity supplied from fossil fuels diminishes when more households and businesses adopt RE technologies.

These findings seem to coincide with the theoretical predictions of demand reduction causes by private RE adoption in the presence of a merit-order supply curve of electricity. The results indicate that coal and natural gas reliance is driven out the most by NEM adoption. All else equal, an increase in the proportion of energy customers with installed RE technologies for NEM programs by 1% reduces utilities' production reliance on coal and natural gas by roughly 1%. Meanwhile, oil reliance diminished by less than half of a percent.

Discussion

Consumer-end RE Adoption and OPS and OPV

The findings of Model 1 indicate that renewable energy adoption through net energy metering programs responds negatively to oil market signals. These results align with the investment literature discussed above in which oil price levels and uncertainty affect anticipated incomes or profits, thereby reducing the expected returns and attractiveness of new investments. If NEM policies were sufficiently constructed to reduce uncertainty about renewable investment returns and to provide attractive financing options for expensive RE technologies, we would see relatively unaffected rates of adoption despite shocks in oil prices are increased price volatility. However, the results of model 1 show that OPS and OPV have very significant effects on private-end RE adoption. A one standard deviation increase in either monthly oil prices or volatility leads to a 6% or 3% reduction in NEM adoption rates, respectively. This is a considerable magnitude of an effect, so we must conclude that NEM policies fail to mitigate the factors contributing to RE’s underinvestment as discussed in Ameli and Brandt (2014).

Had we found OPS and OPV have little effect on RE adoption, we would conclude that NEM adoption reduces payoff concerns for RE investments. The rate of private RE adoption would then entirely be a matter of electricity system size, average energy needs, or prospective RE capacities, and oil market signals would not affect the investment decision into subscribing to NEM programs. Model 1 incorporated these non-oil factors as a predictive component for RE instillations, yet the lagged covariates of oil prices and uncertainty indicate that OPS and OPV still influence investment decision making into RE by businesses and households with NEM programs.

The negative coefficients on the oil covariates could point out various shortcomings in current NEM policies to incentivize private-end RE investment. One explanation could be the state of financing options to opt into NEM programs. Installing solar or wind technologies comes with large purchasing costs or service fees. Financing options such as leasing can be risky if contract lengths are too long or terms and payments are very inflexible. Because of these kinds of factors, setting up RE technologies and joining NEM programs can involve large up-front costs and certain risk considerations can reduce the expected return or attraction towards RE investments. With these risks present in RE investment by energy consumers, it is no surprise that typical investment-limiting economic signals such as oil price shocks or increased volatility reduce uptake into renewable energy. The price and uncertainty signals reduce anticipated incomes or profits and further reduce anticipated returns on prospective investments into RE.

Due to this, smoother RE investment by businesses and households can only be achieved by improving NEM programs or creating new policies that reduce the perceived risks into renewable energy investments by offering a relatively consistent and expected rate of return. Additionally, the financing structures of RE projects for NEM programs should be evaluated. Better financing options, tax breaks, or NEM compensation mechanisms should be implemented to reduce the concerns of upfront investment costs and payoff uncertainties that Ameli and Brandt (2014) note have caused private underinvestment into renewable energy systems. These types of improvements would help the prospective considerations into RE investment and help make rates of RE investment independent of oil market signals.

Nonrenewable Fuel Reliance and RE Adoption

The results of Model 2 then show the impacts of RE adoption and usage on energy systems for utility companies. The findings of these models help identify the margin at which renewable energy reduces certain fuel type usage in supplying electricity. With private-end RE adoption through net energy metering programs, greater uptake decreases reliance on coal and natural gas for energy production. These results therefore suggest that the demand-shifting effects of greater NEM subscriptions are significantly reducing the reliance on fossil fuels, in line with the framework of an energy market facing a demand curve shift with a present merit order energy supply curve.

The greater effects of RE adoption and usage on coal and natural gas reliance is surprising. Given the higher costs of oil-fired generators, we would expect NEM adoption's effect on demand to drive out petroleum fuel reliance the most compared to natural gas and coal. This oddity suggests that utility companies still reserve their reliance on oil-fired generators for sudden spikes in energy demand. In the longer term, the merit-ordering of fuel usage for energy production and the reduction in demand caused by greater NEM uptake by consumers drives out consistently used generators like coal and natural gas since utilities would want to reduce costs in supplying energy. But, for periods of high electricity demand, they do not have a substitutable generator type other than oil-fired plants that can meet sudden energy needs. NEM adoption does seem to mitigate some of the usage, but its impact is smaller compared to coal and natural gas generator types.

As the energy system continues to transition and renewable power grows in popularity for both utilities and private agents, substitute technologies or improved grid management will be needed to replace oil-fired generator reliance. Better energy storage systems or faster production from other fuel types will need to be developed in order to phase out petroleum-produced electricity. As of now, private-end RE adoption is helping drive out reliance on coal and natural gas through long-term demand reductions. While this is beneficial, usage of oil-fired generators is not greatly affected by RE's penetration and involvement in the energy system. Improvements in management, storage, and production technologies will be needed to phase out this other carbon-based fuel in U.S. energy supplies.

Conclusions

This study explored some of the emerging implications for renewable energy's growing popularity within the United States. Unlike fossil fuel energy production, private consumers, such as businesses and households, can adopt renewable energy technologies themselves and help drive the increased role of RE in the electricity system. In this paper, I examine whether private renewable energy investments through net metering programs are impacted by traditional investment-limiting economic factors, such as oil price and their realized volatility. I then analyze the changes in fossil fuel usage in the composition of utilities' electricity supplies as demand shifts occur due to net metering and renewable energy technology adoption.

The findings of this investigation of the U.S. energy system give interesting results. Consumer-end adoption of renewable technologies appears to be inhibited by oil price shocks and realized price volatility. Increases in prices or volatility at around 6 to 9 month lags lead to 6% or 3% reductions in new RE adoptions through utilities' NEM programs. Considerations of credit availability, instillation costs, and payoff mechanisms for RE adoption through NEM policies should be made to mitigate this negative response to OPS and OPV.

From the utility's perspective, NEM adoption's demand reducing effects lead to significant impacts in the composition of energy supplies. A long run merit ordering of electricity supplied by different fossil fuel types appears to be present across utilities, and demand reductions caused by private-end RE investment appears to drive out utility reliance on coal and natural gas for their energy production. Emergency oil-fired generators are fractionally affected by renewable energy adoption compared to coal and natural gas types, and this likely reflects a continued reliance on oil generator types due to a lack of alternative technologies that can meet short-run spikes in energy demand as efficiently and quickly as petroleum-fired plants. Technological innovations will be needed to successfully reduce utility reliance on this third fuel type for energy generation. The U.S. energy system awaits this innovation and the continued growth of renewable energy throughout the NRE-to-RE transition.

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