A qualitative analysis of the short- and long-term impact of residential solar photovoltaic systems on meeting carbon reduction goals in the electric power sector.

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A capstone submitted to Johns Hopkins University in conformity with the requirements for the degree of Master of Science in Energy Policy and Climate

Baltimore, Maryland
May, 2016

Abstract

With the recent sharp increase in growth of residential solar photovoltaic systems, this capstone examines the current understanding of what the integration of these systems means for the electric power system's ability to de-carbonize. Determining any significant consequences residential solar systems have in de-carbonizing the electric power sector should be acknowledged and taken into account in their value proposition. Recent studies on the costs and benefits of residential solar systems and the value of these resources were reviewed as well as interviews conducted with electric power sector experts representing perspectives from electric utilities, independent energy developers, state regulators, the solar industry, government energy researchers, and private energy research and consulting. While there is a good understanding of the potential short-term benefits of residential solar photovoltaic systems, there is difficulty valuing those costs and benefits to the electric sector and there is little understanding of the long-term effects growing levels of these residential systems means for the electric sector in meeting demands of incorporating greater amounts of variable renewable energy generation. A better understanding of the value of the short- and long-term costs and benefits of residential solar photovoltaic systems is needed to encourage residential system adoption rates that allow for de-carbonization goals of the electric power sector to be met efficiently and cost effectively.

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Preface

One of the new electric generating sources helping to flip the electric power sector on its head is distributed residential solar photovoltaic systems. As more customer's adopt these residential systems an increasing tension has emerged with the traditionally monopolistic electric power sector. Adoption of these systems makes customers more independent but is also creating new challenges to a system that simplistically put is use to electricity only flowing one way. There are a few reasons customers may choose to adopt residential solar, and one of these reasons is to address climate change by generating renewable energy. With increasingly vocal criticism of the challenges residential solar is creating the electric sector, I wondered if those challenges could actually in some way hinder addressing climate change, which would contradict the climate-conscious residential solar customer, despite the customer's best intentions. I sought to explore if climate-conscious residential solar owners were indeed helping address climate change, or if in some way their systems were complicating a greater expansion of renewable energy within the electric sector that may have a larger impact on decreasing carbon-dioxide emission in the end.

Acknowledgements

I would like to give an extended thank you to my mentor for this capstone paper, Scott Baker, who provided invaluable feedback, expertise, and discussion. I also want to thank my long-time friend and solar research expert Morgan Putnam for the extended conversations as this capstone was being conceptualized.

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Introduction

The overwhelming acceptance of anthropogenic climate change has driven a conversation about how to limit the amount of carbon dioxide and other greenhouse gasses released into the atmosphere. It's well know that energy-related emissions are the major contributor of atmospheric greenhouse gasses world-wide. In 2014, the U.S. energy sector emitted 84 percent of all U.S. greenhouse gasses (U.S. Energy Information Administration 2016). It's widely believed that in order to change the trajectory of increasing atmospheric greenhouse gasses, energy-related greenhouse gas emissions must be addressed.

Energy-related carbon dioxide emissions from the combustion of fossil fuels make up the vast majority of the energy-related greenhouse gas emissions. In 2014, of all the energy-related greenhouse gas emissions, 92 percent of those were carbon-dioxide emissions due to the combustion of fossil fuels. Methane was the next largest contributor at four percent. Three primary sectors are responsible for energy-related carbon-dioxide emissions: transportation; residential, commercial, and industrial; and electric power. Residential, commercial, and industrial account for 28 percent of energy-related carbon-dioxide emissions, transportation accounts for 34 percent, and electric power accounts for the most at 38 percent (U.S. Energy Information Administration 2016). Of these three, not only does electric power account for the highest percentage, but it is also the most centralized of the sectors, making it easier to target for carbon-dioxide emission reduction.

At varying levels, the electric power sector is being compelled to de-carbonize. It's being compelled both through an increasing desire to address climate change and through the changing economic picture for electric generation sources. As the electric power sector copes with a shifting regulatory environment, changing customer pressures, and a changing economic environment, renewable energy continues to gain traction. One of the tools being used to de-carbonize is distributed solar. As state renewable portfolio standards, regional greenhouse gas compliance, the Clean Power Plan, a potential future price on carbon, and society push for a more de-carbonized electric power sector through renewable energy generation resources, what those resources are and how they are deployed will have consequences. What role does and should the growing deployment of distributed solar resources play in accomplishing the regulatory and societal goals of de-carbonizing the electric sector?

Why de-carbonize the electric power sector?

Regulatory environment

The increasing attention given to climate change over the last two decades has given rise to a new and still changing regulatory environment for the electric power sector. This new regulatory environment largely gives preference to renewable energy generation sources at the expense of heavy carbon-emitting sources like coal. As electric generators consider generation choices, they are now considering a much different planning paradigm that increasingly balances least-cost generation with necessary reductions in carbon-dioxide and other emissions. This has meant a shift from coal generation to greater generation from natural gas and renewables. As the regulatory environment evolves, generation and future planning will need to adapt.

Currently there are a few key regulatory drivers at the federal and state level that have a significant impact on generation choices and planning from the electric power sector. These policies can largely be credited with the gains made by renewable energy. The Mercury and Air Toxics Standards (MATS) and state-level renewable portfolio standards have largely driven the shift in electric generation sources since the late-1990s. There is also the potential for future greenhouse gas regulatory policies, such as the Clean Power Plan, which also need to be considered.

The MATS regulation was finalized in 2012 and went into effect on April 16, 2015. Many utilities applied for compliance extensions until April 16, 2017 (M.J. Bradley & Associates LLC 2015). This rule is largely credited with closing a significant amount of U.S. coal plants. The rule, released by the Environmental Protection Agency (EPA), limits the allowable emissions of mercury and other toxic air pollutants from stationary sources, largely targeting the country's coal-fired power plant fleet that contributed most of these emissions. For some, mostly newer coal plants, it made economic sense to install emissions reduction equipment. For other coal units, the emissions reduction equipment was too costly and it made more economic sense to shut the plant down. Since 2009, the MATS rule has caused over 200 coal plants to be slated for closure (Frazier 2015). With the rule going into effect in 2015, nearly 18 gigawatts (GW) closed in that year alone (U.S. Department of Energy 2016). While the main target was mercury and other air toxics, the significant amount of coal plants retired due to this rule also led to large reductions in carbon-dioxide emissions.

In 2015, the EPA finalized its next significant emissions reduction rule, the Clean Power Plan. This rule targets carbon-dioxide emissions and gives each state a mandatory emissions reduction goal based on the state's specific electricity generation and policy portfolio. The Clean Power Plan leaves the decision up to each state how to meet its emission reduction target by the compliance deadline of 2030. There have been significant legal challenges to the rule and in February the Supreme Court ordered a stay on the rule while the challenges make their way through the judicial process. Despite the Supreme Court's stay, at least 20 states are continuing their planning of their Clean Power Plan compliance plans. Even with this rule in jeopardy due to the Court's stay, the rule is having an effect on the electric power sector and choices of electric generation sources.

Prior to the MATS rule and the Clean Power Plan, states were instrumental in driving the growth of renewable energy generation through renewable portfolio standards (RPS) that called for a certain percentage of the state's electric generation to come from renewable sources. Some RPSs also contain "carve outs" for a minimum amount of generation from a specific renewable source. States did these for reasons of both supporting strong state renewable energy industries and to take actions to decrease carbon-dioxide emissions. Currently, 30 states plus the District of Columbia have renewable portfolio standards. Most of these RPSs are set to be fulfilled by 2025, but they have been a significant driver of renewable energy installations through the early 2000s.

There remain questions on where carbon policy might go in the future and when. In 2009, the U.S. came close to passing and adopting a cap-and-trade policy for carbon-dioxide emissions. While the political environment is different today and doesn't bode well for the adoption of carbon-limiting legislation at the moment, there remain significant policy conversations around a future carbon policy. If the right policy makers align in Congress and the Administration, a carbon policy could come quickly, especially as the acceptance of climate change continues to grow. The electric power sector has recognized the possibility of a future cap-and-trade or carbon-tax policy and knows the effect such a policy would have on the economics of carbon-intense generation. With the life expectancy of generation assets typically 20 to 30 or even 40 years, the electric power sector must already consider the effects of a potential policy on generation asset investments. The electric power sector must not just take these current and future policies into consideration, but it must also take customer demands into consideration.

Societal

The electric power sector is facing increasing pressure from society – and thus its customers – to provide more renewable, less carbon-intense generation choices. Especially in de-regulated states, there are increasing opportunities for consumers to choose that their electricity come from renewable sources. Even in regulated states, increasing public and political pressure is weighing on public utility commissions and utilities themselves. These pressures are increasing as the concern about climate change grows. The emphasis on climate change from its customer base is also pushing the electric power sector to take de-carbonization steps to keep customers happy.

These changing customer preferences are also taking place at a time when customers have more choices regarding where their electricity comes from than ever before. Not only are there an increasing amount of utility programs allowing customers to opt-into renewable energy sourcing, but customers now have more opportunities to generate electricity themselves through distributed energy resources. According to a report by West Monroe Partners, an energy industry business consultant group, "The electric utility industry is accelerating toward a crossroads. Cost-averse and environmentally conscious customers are reducing their dependence on traditional utility generation and creating increased demand for distributed energy resources (DERs). If the market's recent growth is any indication, DERs will become a more important part of the generation portfolio mix in the future (West Monroe Partners 2015)." The continued growth of industrial and residential rooftop solar is the prime example. Customer choice is one of three major trends that are driving the adoption of DERs (Keyes and Karl 2013). More than ever before, consumers are taking the opportunity to generate part of their electricity, ensuring this portion of their electric consumption is from a renewable source.

De-carbonization progress

The electric power sector is de-carbonizing. Regulations and society have largely dictated this trend and it's likely to continue to be the case moving forward. In the U.S., carbon emissions peaked in 2007 at 2,425,000,000 metric tons. This was slightly higher than 2005 when 2,416,000,000 metric tons were emitted. Since 2010, emissions have dropped consecutively every year. Additionally, 2012, 2013, 2014, and 2015 were the lowest carbon emission years since 1996, with 2015 being the lowest at 1,925,000,000 metric tons. From 2007 to 2015 emissions decreased 21 percent. (U.S. Energy Information Administration 2016)

The biggest reason for the reduction in carbon emissions is from the rise of natural gas generation. As the electric power sector added generation or replaced generation from retiring coal plants, natural gas provided a cost-effective, flexible, and less carbon-intensive option. Natural gas generation produces roughly half of the emissions from coal generation (U.S. Energy Information Agency 2015). Over the last 20 years, most of the new capacity added has been natural gas (U.S. Energy Information Agency 2015). The rise of hydraulic fracturing techniques in the U.S. over the last decade that have driven down natural gas prices have also played an important role in the increase of natural gas generation (U.S. Energy Information Agency 2016). Over the last five years, natural gas additions have averaged 7.8 GW. According to the U.S. Energy Information, there are eight gigawatts of natural gas additions planned for 2016, and natural gas generation will overtake coal generation first the first time (U.S. Energy Information Agency 2016).

Wind energy has also contributed to the de-carbonizing of the electric grid. From 2001 to 2014, the installed wind capacity in the U.S. grew more than 1,500 percent (American Wind Energy Association 2015). In 2015, wind accounted for 4.7 percent of total U.S. electricity generation (Energy Information Agency 2016) with over 74 GW of installed capacity (American Wind Energy Association 2016). In 2015 alone, the wind industry added 8.6 GW (American Wind Energy Association 2016) and has another 6.8 GW planned for 2016 (U.S. Energy Information Agency 2016). The extension of the production tax credit at the end of 2015 and its phase out over the next five years until the end of 2019 will help keep momentum on wind additions.

Compared to natural gas and wind, solar makes up a tiny fraction of U.S. electricity generation. In 2015, solar accounted for 0.6 percent of generation (U.S. Energy Information Agency 2016). According to the Solar Energy Industry Association (SEIA), the U.S. currently has 27.4 GW of installed solar capacity (Solar Energy Industries Association 2016). While these numbers represent total solar capacity, it's important to look at specific numbers for utility-scale and distributed solar individually. It's fair to say that utility-scale and distributed solar are in the middle of strong growth trends as the cost of photovoltaic (PV) panels and other solar infrastructure components continue to fall. In 2015, utility-scale and distributed solar combined accounted for nearly 30 percent of newly installed generation in the U.S..

Since 2009, there has been substantial growth in the amount of utility-scale solar installations. Utility-scale capacity grew from around 100 MW in 2009 to well over 4,000 MW at the end of 2015 (Solar Energy Indusries Association 2016). In 2013, 2014, and 2015 a total of 9.4 GW of utility-scale solar was installed, which is less than the 9.5 GW of planned capacity additions in 2016 alone, and more than triple 2015's amount of 3.1 GW (U.S. Energy Information Agency 2016). In 2016, utility-scale solar is expected to exceed additions from every other energy source for the first time (U.S. Energy Information Agency 2016).

Residential solar has experienced similar exponential growth over the past five to 10 years. In 2006, there was around 200 MW of installed residential PV capacity. By the end of 2015 that number was over two gigawatts (Solar Energy Industries Association 2016). Between 2010 and the end of 2015, quarterly residential capacity additions increased more than tenfold. By the first-quarter of 2016, the number of U.S.

homeowners with rooftop solar is expected to surpass the one million mark (Honeyman 2016). Among other factors contributing to the strong growth of residential solar such as falling PV costs and favorable state policies, residential solar PV also received a favorable decision from the Supreme Court. In 2015, the Court ruled to uphold Federal Energy Regulatory Commission (FERC) Order 745 allowing for compensation of demand response resources including distributed solar. This could provide another incentive for residential solar PV adoption. As electric customers look to the economic and sustainable energy benefits, distributed energy sources such as residential solar PV show no signs of slowing down (West Monroe Partners 2015).

Distributed solar background

Solar history

For centuries, mankind has attempted to harness the energy of the sun. Only recently have these efforts turned into harnessing the sun for electricity generation. While some efforts were made on solar energy in the mid-20th century, including the creation of the first ever solar cell developed in the U.S., it mostly wasn't until the 1970s that gains were made. The 1973 OPEC oil embargo and the 1979 oil shock caused the U.S. to rethink its energy strategy. In 1978, the U.S. adopted the National Energy Act that included the Public Utility Regulatory Policies Act (PURPA) and the Energy Tax Act that helped begin deregulation of the electric sector and provided the first renewable energy tax credits.

In the mid-1990s, utility-scale and residential PV installations in the U.S. began to accelerate. President Clinton announced the "Million Solar Roofs" program in 1997 which supported 70,000 PV systems installed by the end of 1999. The 2000s brought the most aggressive solar policies yet as states began adopting RPSs, setting feed-in tariffs and net metering rates, approving power purchase agreements, and creating solar renewable energy credits and tax incentives. Since enacting the 30 percent federal investment tax credit almost a decade ago and the launch of the U.S. Department of Energy's SunShot Initiative in 2011, the cost of all solar energy installations has fallen more than 73 percent (West Monroe Partners 2015). These policies, along with new competition in solar panel markets from China, set the stage for the solar boom that was about to take place. (State of California n.d.)

Technologies

The solar technologies used for residential applications remain fairly uniform. Distributed resources refers to generation located close to energy consumption and are also called behind-the-meter or customer-cited. For residential distributed solar, this means either on rooftops or ground mounted. Most solar panels used for distributed use are similar with only slight differences in electricity production efficiency rates. These efficiency rates will continue to improve as small gains in panel efficiency can make big differences project economics (Wesoff 2015). The typical size for a residential PV system is five kilowatts (kW) (U.S. Energy Information Administration 2015).

Solar panels can be mounted one of three ways: fixed, single axis tracker, or double axis tracker. The way panels are mounted have a significant effect on the system's capacity factor. Single and double axis mounts allow the panels to track the sun throughout the day and seasons as opposed to a fixed or ground mount which is fixed to the same angle or pitch of the roof. While trackers can increase the solar panel's output by 15 to 30 percent, they add complexity, cost, and maintenance that generally does not make economic sense for a residential solar installation (Holladay 2012). According to the EIA, the use of tracking systems is still relatively rare. In California, virtually all residential PV installed in 2014 was on fixed mounts (U.S. Energy Information Administration 2014).

Utility-scale projects approach the technology decisions differently than an residential solar owner. Utility-scale projects are often developed under certain space limitations meaning solar energy output maximization is more important for reliability and cost-recovery. This makes more expensive, higher efficiency panels and tracking systems worth the extra cost in return for the higher capacity factor. These extra costs usually don't pan out for residential solar because of the cheap cost of basic silicone panels. If a rooftop solar project desires more energy output, it can be more cost effective to merely add more panels on the roof than invest in additional technologies. In the end, these differences mean higher generation rates for utility-scale PV. The EIA says, "Utility-scale solar PV systems have higher generation rates than small-scale solar PV systems, likely because of more favorable siting and orientation, better maintenance practices, and a higher proportion of systems with sun-tracking features that allow for increased generation (U.S. Energy Information Administration 2015)."

Where is residential solar prevalent?

Rooftop solar is becoming more competitive across the U.S.. Favorable residential solar policies and installed costs decreasing on average from just under 7 dollars per Watt in 2010 to 3.50 dollars per Watt in 2016 have caused residential solar to reach grid parity in 20 states (Honeyman 2016). In the current pricing and policy landscape, this number is expected to rise to 42 states by 2020. A 2016 Greentech Media study on the outlook of residential solar says, "…through 2020, incremental cost reductions to rooftop solar, alongside incremental retail rate hikes in most utility service territories, will serve as sufficient tailwinds to expand the number of states that reach grid parity from 20 to 42 states (Honeyman 2016)." However, just because these states are at or near cost parity, doesn't mean that these states have significant residential solar installations. Some of these states are only recently at cost parity and residential solar adoption is just starting to grow, or some states have regulatory challenges that create an uncertain business environment.

The top ten states make up 84 percent of the U.S.'s total distributed solar capacity (U.S. Energy Information Administration 2015). This number includes non-residential distributed PV, but nonetheless a good indicator. An important distinction is made with this list of top distributed PV states compared to the list of top states for total solar capacity which includes utility-scale and solar thermal projects. Together, the top ten states for total solar capacity account for 87 percent of installed U.S. solar capacity (Solar Energy Indusries Association 2016). For distributed PV, California accounts for 40 percent of the entire U.S. market and is followed by New Jersey, Arizona, Massachusetts, and New York. (U.S. Energy Information Administration 2015). California also tops total installed solar capacity accounting for nearly 50 percent of the U.S.'s solar generating capacity and is followed by Arizona, New Jersey, North Carolina and Nevada.

The differences between the lists of top producing states for distributed PV and total solar capacity highlights important differences in considering the growth of residential PV and utility-scale. According to the U.S. EIA:

> The mix of utility-scale versus distributed generation solar PV varies by state, often reflecting differences in state and local policies. For instance, 94% of North Carolina's 1,070 MW of installed solar capacity is utility-scale systems. In states like New York and Hawaii, distributed generation solar PV systems are more prevalent than utility-scale systems, making up 87% and 89%, respectively, of the total solar capacity in those states. (U.S. Energy Information Agency 2015)
>
> [Besides California] Other top states share some but not all of these factors. New Jersey, Massachusetts, and New York are top distributed solar states despite relatively less favorable solar resources because of consistent state solar PV policies and incentives and some of the highest residential electricity prices in the country. Other states, like Arizona, have incentive programs and strong solar resources. Hawaii has a small population, but its strong solar resources and high electricity prices make rooftop solar PV systems economically attractive. (U.S. Energy Information Administration 2015)

These policy drivers are instrumental in the adoption of residential PV in states where the solar resource is not as strong as in places like the Southwestern U.S., and are also forcing system operators in these areas to asses what more concentrated growth of residential solar means for their systems. While the distribution of residential PV is currently lopsided to certain states, the Solar Energy Industries Association says the residential market is showing signs of diversification (Solar Energy Industries Association 2016). This bring more operational challenges to more system operators.

Distributed solar incentives and rate structures

Solar policies have played a key role in solar adoption and where solar has grown the most. In late-2015, the federal investment tax credit (ITC) was extended through 2021. The extension keeps the ITC at 30 percent through 2019, then ramps down to 26 percent in 2020 and 22 percent in 2021. After 2021, the credit will be eliminated for residential solar installations and remain at 10 percent for commercial installations. The ITC was initially adopted in the Energy Policy Act of 2005. This policy was important to decrease the installation costs of solar, helping strengthen the market and reach economies of scale. While the ITC has increased the economic attractiveness of solar projects for both utility-scale and distributed users, solar adoption is also dependent on state policies and net metering rates.

Across the country there are a variety of different solar PV incentive policies in a multitude of states. Some states have multiple policies that can be combine including state tax credits, rebates, and loan assistance. Additional assistance may also be available from specific municipalities within the state. The amount of solar incentives in a state, including municipal incentives, has a wide range from 84 in California to two in Wyoming (North Carolina Clean Energy Technology Center n.d.).

Another major state policy driver since the mid-2000s is the widespread adoption of state renewable portfolio standards (RPSs). These laws mostly require utilities to generate renewable energy or purchase renewable energy credits (REC) equal to a certain percentage of retail energy sales. Currently, 29 states, the District of Columbia, and three U.S. territories have adopted RPSs. Of those, about half of the RPSs have a specific carve out or set-aside for solar, mandating that a certain portion of the RPS be met with solar resources. Additionally, a few states require part of their RPSs to be met with distributed resources (Durkay 2016). These specific carve outs were important in creating markets for utility-scale and residential PV, and accelerating technological development.

While these policies helped customers defray installation costs and accelerate technological development and market penetration, these policies did not necessarily help consumers deploy solar themselves. The rise of net metering policies alongside these other solar incentives has had a significant impact on residential PV adoption and has come under increasing scrutiny with the boom of residential installations. According to the Interstate Renewable Energy Council, "NEM has proven to be one of the major drivers of distributed generation…The success of NEM as a policy to drive distributed generation market growth has caused several states to examine the impact that the policy has on other non-participating ratepayers (Keyes and Karl 2013)."

Net energy metering (NEM)

NEM policies started to spread throughout the 1980s with public utility commissions in Arizona and Massachusetts adopting the first of these. Minnesota soon after adopted the first net metering law. Seven more states would follow suite by 1988. For distributed energy resources, net metering compensates the owner of the distributed system for any excess electricity produced that is not used on-site and thus flows back onto the electric grid. It essentially works by a customer's electric meter spinning one way for electricity used from the grid and by spinning backward for excess electricity it sends back to the grid, decreasing the customer's overall electric bill. Net metering largely started as an act of convenience to avoid the need of installing an additional electric meter, but not long after utilities were beginning to recognize net metering as a threat to the electric utility business model.

Even with NEM adoption beginning in the 1980s, compensation for electric production from small facilities was already required by PURPA. According to the National Renewable Energy Lab (NREL):

> Pursuant to rules authorized by the Public Utility Regulatory Policy Act of 1978 (PURPA) and promulgated by FERC, electric utilities must offer to purchase electric energy from small power production facilities of 80 MW capacity or less… Furthermore, the FERC rules require each utility to offer standard rates for purchases from all qualifying facilities with a design capacity of 100 kW or less. Utilities have discretion on whether to offer standard rates or to negotiate rates for purchases from facilities larger than 100 kW. (Bird, et al. 2013)
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> These PURPA requirements and FERC rules are relevant to the discussion of distributed PV because almost 98% of PV installations in the United States are smaller than 100 kW. Although the number of larger installations is expected to grow, many PV installations will likely continue to fall under the PURPA facility limits. Thus, utilities must offer to purchase the output from these qualifying distributed PV systems through a standard rate tariff that is just and reasonable. (Bird, et al. 2013)

The Energy Policy Act of 2005 (EPACT) amended PURPA by stating that each, "electric utility shall make available upon request net metering service to any electric consumer that the electric utility serves" and directs all state utility commissions and non-regulated utilities to consider adopting a net metering standard (Flores-Espino 2015).

With a growing number of net metered customers, there are increasing concerns - primarily from utilities - about what a greater amount of NEM payments means for the utility business model. On the other hand, net metering rates have remained fairly stable over the years and a change in compensation to PV owners could constrain PV expansion and even potentially harm current PV installations. In 2014, legislators in 29 states introduced legislation to amend net metering provisions and that number became 33 in 2015 (Flores-Espino 2015). In December of 2015, Nevada regulators approved the first successful NEM rate change reducing the NEM rate from the retail price of electricity to the wholesale price (Shallenberger 2016). The Public Utilities Commission of Nevada also approved increasing fixed costs and denied grandfathering in existing residential solar customers with the old NEM rate (Walton 2016).

The rapid adoption increase of residential solar PV in the last half-decade has raised questions of if NEM policies, which compensate customers at the retail rate, are too generous and thus unfair to the utility. At very low levels of distributed solar penetration there is minimal effect of NEM payments on the utility. However, NREL found instances that when net metered PV produced 2.5 percent and above of total retail sales it could have negative effects on a utility's earnings and shareholder returns (Flores-Espino 2015). Up to 10-25 percent of a customer's power bill is made up of non-energy consumption charges (Honeyman 2016). If a PV customer's NEM credits are worth most or all of the electric bill, this means the utility is also not recovering those non-energy use charges. This has prompted some utilities to propose new rate-structures to recover lost revenue. According to NREL, "The circumstances that have triggered the recent push for change include a growing percentage of net-metered customers, potential effects of distributed generation on cost allocation, decreasing photovoltaic (PV) system costs, the challenges of integrating high levels of solar generation in the distribution network, and increasing pressure on utility business models (Flores-Espino 2015)."

With the rise of these concerns, new rate designs have emerged as options for utilities to consider. These changes include fixed monthly charges, demand and standby charges, and changes of the value solar customers receive for excess energy sold back to the grid (Flores-Espino 2015). A study conducted by Greentech Media on residential solar grid parity shows that these types of new rate structures being considered would have a significant effect on the number of states currently at grid parity. The study shows a 50 dollar fixed charge would cause the number of states at grid parity to fall from 20 to two, while a 10 dollar fixed charge would drop the number to 15 states (Honeyman 2016). This is the exact debate that has emerged in Arizona where two utilities are attempting to implement residential demand charges on rooftop solar customers causing SolarCity, the market-leading residential solar company, to file a lawsuit claiming the new rate structure discriminates against rooftop solar users. SolarCity claims the new 50 dollar fixed distribution and residential demand charge has caused a drop in applications for rooftop solar in the utility's service area by 96 percent (Shallenberger, Are residential demand charges the best rate reform for DERs? 2016).

Another rate structure change being discussed is how to properly value and compensate residential solar PV customers for excess energy sold back to the grid. Right now, NEM rates are pretty uniformly equal to the retail rate of electricity. Like the debates around the implementation of fixed charges in Arizona, there is a similarly contentious debate around changes to NEM in Arizona and in Nevada where regulators recently cut the NEM rate from the retail rate to the wholesale rate. The changes made in Nevada remain controversial and both sides of the issue remain heated (Walton 2016). Just like fixed charges potentially greatly reducing the demand for residential PV systems, the solar industry expects similar decreases in residential solar adoption in states that do decrease NEM rates for customers.

The increase over the past few years in conversations about and efforts to reform distributed generation compensation has raised questions about the effects of the sharp increase in rooftop solar deployment on utilities' bottom lines. As these conversations and reform efforts are taking place, there is not yet a consensus on what those reforms or NEM rates should look like. With a high potential for implications of any reforms for either utilities or the rooftop solar industry, some, including states, public utility commissions, and utilities and residential solar companies themselves are attempting to quantify the costs and benefits of these residential solar systems so they can make a strong case for, or defend against, rate structure reforms. One of the ways this is being done is through Value of Solar (VOS) studies. The idea of these studies is to adequately quantitate the costs and benefits of residential solar PV so that rooftop solar customers or utilities can be compensated fairly. The value established may then take the place of a NEM rate as something called a VOS tariff. This has been done by Austin Energy in Texas and something similar was passed into law in Minnesota. Instead of adding additional fixed costs, demand charges, setting a minimal bill, or lowering NEM to the wholesale rate, a value of solar tariff attempts to find the real value or cost of those solar resources on the system. (Flores-Espino 2015)

Rise of third-party ownership (TPO) models

The dramatic increase of rooftop solar adoption over the last half-decade has been almost entirely customer driven. Favorable solar policies and falling solar panel prices have helped give customers the opportunity to install residential solar systems for any number of reasons including reduced energy costs, environmental benefits, and energy security. Whatever the reason for adoption, more customers are making the decision to install residential solar systems. Possibly the biggest development, however, leading to increased levels of residential solar adoption is the rise of the third-party owned (TPO) lease and power purchase agreement (PPA) structure and business model. According to SEIA, "Third-party financing allows more Americans to "go solar" by lowering the cost of solar installation and maintenance of a system (Solar Energy Industries Association n.d.)."

Still relatively new, the TPO financing model was pioneered in 2006 by SunEdison and Renewable Ventures and was quickly adopted by other developers (Kollins, Speer and Cory 2010). Since the creation of this model in 2006, rooftop solar installations have grown rapidly and TPO has become one of the most popular methods of solar financing (Solar Energy Industries Association n.d.). In some U.S. solar markets, TPO has been used for 70-90 percent of new installations in recent years (Davidson 2015). However, third-party ownership faces some regulatory barriers and uncertainties. Currently, third-party ownership is authorized in 24 states plus the District of Columbia and Puerto Rico. In five states the practice is disallowed and in the rest of the states the status remains unclear or unknown (Davidson 2015). The biggest barrier is typically how a state defines "utility" and the consequences for who is allowed to sell electricity.

The TPO financing model broke down the biggest barrier to rooftop solar adoption: the high up-front capital costs. The TPO PPA model, and later the TPO leasing model, would shift the high up-front costs to an entity with greater access to capital and that could better utilize solar tax incentives. The PPA model allows a developer to own a PV system on a customer's property and sell the electricity back to the customer, usually at prices less than utility retail rate. The TPO lease model came about as an alternative to the TPO PPA model with some states having policies that restricted the use of PPAs by non-utilities. This model allows the customer to lease a PV system from a developer while the customer consumes the energy onsite or net meters any excess back to the grid. (Kollins, Speer and Cory 2010)

The rise of the third-party ownership model led to the creation of third-party ownership residential financers. In 2014, 72 percent of installed residential PV systems were third-party owned in the form of PPAs and leases. That number is expected to decline, but will remain above 50 percent of installed capacity through 2019. There are a number of residential solar financing companies that have emerged along with the TPO model, but the market is dominated by three: SolaryCity, Vivint Solar, and Sunrun which in 2014 accounted for 34, 12, and 10 percent of installed capacity respectively. The TPO model has been instrumental in opening the door to customers for residential solar and a big cause in the steep rise in residential solar adoption. (Munsell 2015)

What does the growth of rooftop solar mean?

Utility perspective challenges and benefits

Electric utilities aren't ignorant to the growing adoption of rooftop solar systems and they are right that there are concerns that must be addressed within their systems as residential solar penetration grows. With the increase in rooftop solar systems, utilities are essentially having to deal with a new way their systems work and behave. Utilities are learning to deal with an electric grid where electricity now flows two ways instead of just one. This means new technologies and software must be adopted, new hardware deployed such as smart inverters, and new ways established of looking at system operations. According to a study by the Solar Energy Power Association and Black & Veatch:

> The growth of DERs is challenging many of the assumptions upon which traditional distribution planning relies. DERs are creating two-way power flows on the distribution system that legacy distribution equipment was not designed for. DERs are also confounding conventional load forecast methodologies and complicating the modeling of distribution feeders by introducing new kinds of generation sources or modifying load profiles. (Colman, Wilson and Chung 2015)

While the coasts of installation and connection mostly fall on the customer, the utility is left with integrating those resource into the rest of its operations.

The increasing penetration of rooftop solar also means grid operators have to deal with more and more variable generation resources on their system. Variable generation itself provides challenges to the electric system that utilities are still learning to deal with as more solar and wind resources are adopted. However, residential assets provide one more layer of complexity to the variability issue in that grid operators can't see what's happening with that generation unit. The RTO only sees the the corresponding generation system as load (Federal government policy executive with regional transmission organization 2016). Until grid operators are able to have more visbility with what's happening with these generation sources they act similarly to giant light switches that can be turned on or off in a moments notice, causing big shifts in load, without the grid operator knowing.

Above all, utilities' top operational concern is system reliability. Growing penetration levels of rooftop solar is cause for more questions as much of this is still relatively new for system operators to handle. NREL recognizes the learning curve that grid operators still face:

> To enable the creation of equitable solutions in the future, some gaps in knowledge warrant attention. For example, the benefits and costs of distributed PV at higher penetration levels are not fully understood yet; therefore, additional efforts to identify and quantify system effects are needed to ensure equitable solutions. (Bird, et al. 2013)

Supporters of greater distributed solar PV adoption are quick to point out the benefits distributed resources can bring to an electric system. Often times, the distributed solar industry mentions the ways in which rooftop solar can make the grid more reliable. However, one utility market and analysis expert emphasized the reliability concerns saying that the distributed solar industry may downplay this, but if the power goes out on customers, they are mad at the system operator (Market and analysis expert with major east coast utility 2016).

There are at least a couple of benefits of distributed solar PV that the utility industry acknowledges. Operationally, distributed generation can reduce transmission demands. This can extend the life of transmission infrastructure, but it can also help reduce transmission congestion depending on its location and allow for more efficient operation of the grid system. The other benefit that can’t be ignored is distributed solar’s ability to help utilities meet regulatory requirements either for renewable energy generation and/or emissions reduction. Even though utilities likely would prefer utility-scale solar to meet requirements, at some point it’s all solar counting toward the same compliance standards.

Utility business model challenges

Besides operational challenges, utilities are also facing challenges to their business models with increasing rooftop solar adoption levels. The utility business model is mostly based on two aspects, a customer's utility bill and the assets the utility owns. Utilities charge customers for the costs to generate the electricity consumed and for transmitting that electricity to the point of use. Built into electricity rates is also a reasonable return on investment for assets that the utility owns to accomplish its generation and transmission obligations. Rooftop solar expansion threatens to chip-off from both aspects.

As mentioned above, one business model threat utilities are experiencing is NEM itself. Depending on a rooftop solar customer's daily load and time of energy consumption, a rooftop customer could send back a substantial amount of energy to the grid which the customer will be compensated for at the full retail electricity rates. These NEM credits are reflected on the customer's energy bill and if the customer has sent enough electricity back to the grid, that bill could be zero. This means that while the utility is having to generate less electricity, it's not recovering other costs that are reflected in the customer's electric bill such as transmission or asset return.

The other aspect of the utility business model is the ownership of it's electric assets. When a utility needs to build new electric infrastructure, either generation or transmission, the utility receives a return on that investment. The growth of rooftop solar systems means that the utility might not need to build as much new infrastructure either because there is less generation need or because there is less demand on transmission and thus transmission investments can be deferred. A study by SolarCity, the leading rooftop solar provider, captures the framework utilities operate in:

> Despite this potential value from embracing a distribution-centric grid, utilities face institutional barriers to realizing these benefits. Reducing the size of a utility's ratebase – its wires-related investments – cuts directly into shareholder profits. Expecting utilities to proactively integrate DERs into grid planning, when

> doing so has the potential to adversely impact shareholder earnings, is a structurally flawed approach. It will be impossible to completely capture the potential benefits of DERs until the grid planner's financial conflict with the deployment of DERs is neutralized. (SolarCity 2016)

One solution to this being considered and even beginning to be attempted in the utility sector is utility ownership of rooftop solar assets. This way the utility would continue to expand ownership of electric assets and the utility would also have more information coming from these systems (Bird, et al. 2013). Along with ownership, however, comes increased business costs such as maintaining these distributed resources that may prove prohibitive.

The operational and business model challenges are real for utilities, but there's not much evidence that those challenges can't be overcome. Not long ago grid system engineers were saying that the electric system could accept zero intermittent resources, but the system is way beyond that now (Minnesota energy regulator 2016). A director with an independent energy development company said that it's not that the utilities can't adapt to greater residential solar resources on the system, but there is pushback because they don't like it and utilities see distributed generation as a nuisance that they have to plan around. Some of this concern is utility culture and some of it is legitimate reliability and safety concerns. However, only a small percentage of utilities are proactively planning for greater rooftop adoption. Additionally, as the electric sector undergoes changes, there will be lots of infrastructure investment and the debate right now is who (customers or utilities) will be making that investment. (Director, Legislative and Government Affairs at an independent energy development company 2016)

Distributed solar industry perspective challenges and benefits

For individual rooftop solar PV systems, few challenges exist. Electric production and grid connection are fairly standardized and there is not much the residential system owner needs to be concerned about. The rest of the challenges are left to the system operator. The residential solar industry, however, has downplayed concerns from the utility side about integration and variability and lists many benefits that the deployment of residential solar brings to the grid and grid operators (Beach 2016). These potential benefits include relieving transmission constraints and meeting regulatory requirements, but they also include reduced electric losses because of placement at or close to load, and have the potential to provide voltage support and meeting frequency requirements. The key to recognizing many of these benefits is the use of smart inverters which largely still need to be deployed and are expected to drop 50 percent in price over the next decade (Colman, Wilson and Chung 2015). A February 2016 white paper by SolarCity entitled "A Pathway to the Distributed Grid" lays out some addition benefits the distributed solar industry sees that distributed solar systems provide utilities and customers. A few of these are summarized below:

> We [SolarCity] find that an electric grid leveraging DERs offers an economically better alternative to the centralized design of today. DERs bring greater total economic benefits at lower cost, enable more affordability and consumer choice, and improve flexibility in grid planning and operations, all while facilitating the de-carbonization of our electricity supply.
>
> DERs (distributed energy resources) can provide value by reducing the electric demand in the market, leading to a reduction in the market clearing price for all consumers of electricity.
>
> DER solutions that can preserve reliability, while delaying capital investments for new capacity until future periods, are inherently valuable to ratepayers. (SolarCity 2016)

One of the biggest benefits that the distributed solar industry touts is the benefit of customer choice. These choices have largely been missing from the electric grid with the historic monopolistic structure (Research engineer with U.S. Department of Energy's national laboratory 2016). This is part of the pushback from utilities in the sense that it's not solely their generation planning process anymore. Utilities argue that they shouldn't have to buy excess generation from a rooftop solar system at the retail NEM rate when they could buy those same electrons from another source – utility-scale solar or otherwise – at the wholesale rate.

Value of Solar

The value of solar studies conducted have taken a look at what a reasonable rate of compensation is for rooftop solar PV owners and may be used in or to propose a VOS tariff. While the idea behind these studies is to establish a specific compensation amount, these studies are telling much more. These studies have often followed the politically charged rate structure change discussions and proposals. The reason mainly is that there is no uniformly accepted method and criteria used to produce these studies and thus the compensation value discovered by each study varies. According to a Rocky Mountain Institute study:

> Today, the increasingly rapid adoption of distributed solar photovoltaics (DPV) in particular is driving a heated debate about whether DPV creates benefits or imposes costs to stakeholders within the electricity system. But the wide variation in analysis approaches and quantitative tools used by different parties in different jurisdictions is inconsistent, confusing, and frequently lacks transparency (Hansen, Lacy and Glick 2013)."

NREL also acknowledges the differences in costs and benefits and the lack of consensus on methodology (Bird, et al. 2013). With conflicting values and processes being used in these studies, there is more interest in trying to figure out what that uniform evaluation process is and thus actually pinning down and placing a value on those residential solar resources that's reflective of long-term and short-term benefits.

Placing a value on rooftop solar resources is not easy and no single tool exists today to accomplish that (Denholm, et al. 2014). While merely capturing the variations mentioned above is difficult, there are yet other factors that are recognizable but are difficult to quantify and monetize. The Rocky Mountain Institute says:

> These categories of costs and benefits differ significantly by the degree to which they are readily quantifiable or there is a generally accepted methodology for doing so. For example, there is general agreement on overall approach to estimating energy value and some philosophical agreement on capacity value, although there remain key differences in capacity methodology. There is significantly less agreement on overall approach to estimating grid support services and currently unmonetized values including financial and security risk, environment, and social value. (Hansen, Lacy and Glick 2013)

From the list above, environmental, security-risk, financial, and social can be difficult to quantify. While all these other factors are important, there is an overlap between two of these where the importance of the value should go beyond the utility and the regulator, but also to the customer who is deciding to install a residential solar system. The environment and societal categories, while encompassing more than carbon-dioxide emissions, distinctly overlap on the carbon-dioxide emissions point when it comes to the deployment of residential solar. Carbon-dioxide emissions are an environmental factor that contribute significantly to climate change. Climate change, and thus carbon-dioxide emissions, is an issue society is increasingly caring about and is shown to be a major reason in the growing adoption of rooftop solar systems (West Monroe Partners 2015). It is important for the consumer, along with the utility and regulator, to understand the value of rooftop solar systems in de-carbonizing the electric sector and thus mitigating climate change.

Analysis

Residential solar adoption has taken off over recent years with significant growth taking place since 2010. This growth was not accidental even though it might be surprising to some. The increased adoption rate of residential solar has sparked discussions about how those solar resources will be incorporated into distribution systems across the country - distribution systems that are becoming more de-carbonized by the day - and how to value those solar resources. The discussion above about the current context of residential solar in the U.S. is important in attempting to decipher what role residential solar systems should play in de-carbonizing the electric sector.

Only recently have residential solar resources played a more noticeable role in the electric sector. Because of regulations, shifting fuel prices, strong renewable energy policies, and societal pressures, the electric sector is already on a de-carbonization path. At the same time, the combination of customer preferences, dropping solar panel prices, new TPO business models, and strong solar or distributed energy specific policies has elevated the role of solar resources on the electric system. The rising role of residential solar PV is causing the electric sector to take a serious look at what these resources mean as they come onto grid systems and the costs and benefits they provide. According to the Interstate Renewable Energy Council:

> …economic and policy pressure on rebates and other mechanisms to foster DSG (distributed solar generation) penetration has increased interest in improving understanding of the DSG value proposition. Utilities, policymakers, regulators, advocates, and service and hardware providers share a common interest in understanding what benefits and costs might be associated with such increased deployment of DSG, and whether net benefits outweigh net costs under a variety of deployment and analysis scenarios. (Keyes and Karl 2013)

With uncertainty about how residential solar plays into electric system reliability and the potential threat of these resources to utility business models, there is increased interest in attempts to evaluate what the true value of these solar resources is. What is clear from these value of solar studies (VOS) is the lack of consensus on the factors to consider and methodologies leading to a range of solar values. What is also clear from these VOS studies and through conversations within the electric sector is that there is not yet an of understanding of what the increase of residential solar PV resources means to long-term to grid operations amidst an increasing de-carbonization of the electric sector. If the goal of regulations and the increasing concern of society is to push for a greater de-carbonized electric sector, it seems important to know the value of residential solar in helping to accomplish that goal in the end.

In the current landscape, the immediate de-carbonization value of residential solar is a bit clearer. Current installations of residential solar PV are directly offsetting generation from fossil fuel sources. To grid operators, residential solar is considered a negative load, meaning there is less demand needing to be met by dispatching conventional generation. Every residential solar system generating electricity cuts into, or fully displaces, marginal wholesale generation sources. Broadly speaking, the generation likely on the margin is natural gas. In that sense, residential PV is eliminating emissions from a natural gas plant.

The other way that residential rooftop PV is demonstrating value to the de-carbonization process is by delaying or eliminating the need to build more generation capacity. Planned electric generation capacity additions is still dominated by natural gas, accounting for 58 percent of new capacity through 2040, even though the total amount of necessary capacity additions is shrinking (U.S. Energy Information Agency 2015). As long as residential solar PV is blocking additional fossil fuel capacity from being built, there is substantial de-carbonization value.

Eliminating energy produced by, and thus emissions from, the marginal generating source and delaying planned natural gas capacity expansion are the current de-carbonizing benefits of residential solar PV. These benefits are already happening with deployed residential solar PV and have a role in the de-carbonizing of the electric sector that should be acknowledged and valued. Although increasing rapidly, the still low percentage of total generation that residential solar PV accounts for hasn't yet posed any insurmountable challenges to the electric sector. At least in the short-term and when fossil fuel generation is on the margin, residential solar PV is being used and should continue to be used in the de-carbonization process.

The question of what role role PV should play in de-carbonizing the electric sector gets trickier when a residential solar versus utility-scale solar comparison is made. The focus here is comparing residential PV to utility-scale solar, but a similar type of discussion could be had with utility-scale wind. The discussion of residential solar versus utility-scale PV moves beyond just direct carbon-dioxide displacement from one source or the other and into one on economics, timing, and long-term system capabilities.

Having a more de-carbonized grid requires investments in more carbon-free resources. In comparing utility-scale solar with residential solar, the short answer is that residential solar PV is not the most economical choice (Federal government policy executive with regional transmission organization 2016). Utility-scale solar is cheaper per ton of carbon-dioxide reduced (Minnesota energy regulator 2016) and is the default for what is more economically efficient because of having a better capacity factor (tracking, multi-layer panels) and it's better for the commercial investment process because it risks capital at the right rate and minimizes costs (Research engineer with U.S. Department of Energy's national laboratory 2016). However, while in a general framework utility-scale solar appears to be cheaper, utility ratepayers are ultimately who pay those costs. With residential solar, society (ratepayers) is not paying for this source, the homeowner is and society is only paying for any incentives or NEM payments (Research engineer with U.S. Department of Energy's national laboratory 2016).

On a levelized cost basis, as of 2014 utility-scale solar was still well below half the levelized cost of residential solar (Lazard 2014). This is one of the cornerstones of the debate from the utility perspective on why there should be reforms to the NEM rate. While not necessarily in the sole context of costs to de-carbonize, residential solar is more expensive for the utility and thus potentially increases costs for other customers on the utility's system. Tucson Electric Power is one of the Arizona utilities asking for a reformed NEM rate. It's CEO, David Hutchens, laid out how he views the cost differences to the electric industry publication Utility Dive earlier this year:

> If you give us [the utility] extra solar [from residential], we could have just bought that for 6 cents or 5.8 cents [from the wholesale market] is what we filed. Why would we give you ten or twelve cents for it [through NEM]?" Hutchens said…"We're comparing it with ... the larger, community-scale stuff, which is

> half the cost, sitting right in our community. The only difference is it's not on a roof," he said. "It's on our distribution system, we can plan where to put it, we can control the output, so there's a lot of benefits there. (Bade 2016)

In response to those type of comments about the utility having to buy 10 or 12 cent solar instead of six cent solar, the other side of the equation must also be considered. Why should customers have to pay a retail rate of nine or 10 cents for their electricity when they could generate it themselves for six cents? As a residential customer, self-generation is now an option. This dynamic has long been missing. (Research engineer with U.S. Department of Energy's national laboratory 2016)

Pro-residential solar advocates argue that levelized cost analyses don't take enough factors into account. They argue that the costs are much similar once the avoided transmission costs and other grid-services provided by residential solar PV are taken into account. An opinion piece from the Institute for Local Self Reliance says, "There's nothing wrong with building utility-scale solar. But let's be clear: it's neither the most economic nor the fastest way to green the electricity sector, and it cements centralized control of electricity system in an era of widespread decentralized innovation. And that may be too high a price to pay (Farrell 2015)." There are costs and benefits of residential solar and utility-scale solar to be weighed. This to a large extent is what VOS studies are trying to accomplish, they are trying to give value to those factors not included in traditional levelized cost of energy analysis.

Costs matter because de-carbonization of the electric sector will not be cheap. If one generation source costs twice as much as the other and provides the exact same de-carbonization benefit, that source should be used to accomplish de-carbonization goals. That would be the responsible decision to society and provide the most equitable treatment of all ratepayers. Different generation sources don't provide the exact same benefits just like residential solar and utility-scale PV provide some different benefits. However, depending on how close those benefits are to each other, only a certain differential of cost is reasonable. Passing up the perceived cheaper resource without an understanding of both resources' full values means leaving funding that could go toward yet more de-carbonization generation or to other societal goods on the table. For this it is critical to continue working on value of solar methodologies so policy makers and society can use that information to best decide what role residential solar should play in the de-carbonization of the electric sector.

One consideration is how quickly policy makers and society want the de-carbonization to happen. If addressing climate change is the key driver of these goals, then de-carbonization should either happen at the pace the Intergovernmental Panel on Climate Change (IPCC) has established which is 40-70 percent below 2010 emission levels by 2050 and zero emissions by the end of the century to keep temperature increases under 2 degrees Celsius, or faster (Thompson 2014). Depending on the pace of de-carbonization desires, it's important to value which type of generation source can accomplish de-carbonization in the desired timeframe.

The value given to timing is straight forward; the faster a project can be built and producing electricity that replaces carbon-dioxide emissions on the grid, the greater the value. Again taking a look at utility-scale solar versus residential solar, utility-scale solar is the default higher value. Most electric-sector experts would agree that the most effective way to accomplish de-carbonization is through utility-scale as de-carbonization can happen much more quickly (Minnesota energy regulator 2016) (Research engineer with U.S. Department of Energy's national laboratory 2016).

There are some, however, who do believe that residential solar PV can be deployed more quickly than utility-scale. While residential solar can't compete on the scaling-up of a project, it can be sited very quickly. With individual property owners making the decision about whether to install PV or not, there are fewer regulations to meet because of property ownership and size of the project. Utility-scale projects can take years to develop, dramatically slowing down the "readiness" of utility-scale solar to be deployed. However, enough rooftops are needed to equal the same generation capacity. For a 100 MW solar PV farm, about 200,000 rooftops would be needed to equal the generation. Especially given the rise in popularity, a substantial amount of residential solar could be added quickly to the electric system even while larger, utility-scale projects were under development.

If residential solar PV is occupying generation space on the grid that utility-scale projects otherwise would, what does that mean for the system on whole? How does that change system operations and how does that play into a system that is being filled with more and more variable resources? The answers to these types of questions should be equally, if not more valuable to the role that residential solar should play in de-carbonizing the electric sector. The emissions reductions from the currently deployed residential solar systems are valuable in the de-carbonization process, but it is still less than one percent of total generation, a small fraction of what it might be someday. Again, if the goal being pursued is the de-carbonization of the electric sector, then it's critical to know and value what higher penetration levels of residential solar mean for a system that is becoming increasingly more renewable and intermittent.

More specifically, there is difficulty quantifying the costs and benefits of residential solar to a future with a more de-carbonized electric sector. The benefits of de-carbonizing are generally taken as the amount of carbon-dioxide residential solar PV systems reduce multiplied by some value – a social cost of carbon, a hypothetical future price on carbon, or equal to the value of carbon credits in an established carbon market. This calculation only accounts for the carbon-dioxide displaced that would have been emitted by a carbon-based generating source and only considers the displacement from that individual solar PV system. The calculation does not include the costs and benefits to the efficiency of transitioning to and accomplishing a de-carbonized electric sector.

If a renewable generation source makes it easier or harder to incorporate higher and higher penetrations of renewable energy on the electric system, that should be accounted for in its valuation. Consumers do this all the time. If a goal for a consumer is to replace a furniture set over a few years piece by piece, the first piece the consumer purchased would likely be the same style of the rest of the pieces so they would all fit together in the end. The same would be true for a consumer buying a new home entertainment system, knowing which pieces to buy so they all connect seamlessly together. If they don't, the consumer may have to acquire additional system adapters or suffer a lower sound and/or video quality. The same idea should be applied to transitioning the electric sector to a more de-carbonized one.

As the electric system becomes more intermittent with renewable sources, do higher penetrations of residential rooftop solar PV complicate the addition of more renewable, intermittent resources? Does it aid in greater adoption of intermittent renewable sources? Does it matter? With solar and wind making up only about six percent of the U.S. electric generating capacity and large growth projections predicted for both, there are more de-carbonization efforts on the line that may or may not be hamstrung by the generation sources chosen today. These types of questions should be considered by utilities, policy makers, and society (consumers) to ensure the greatest possibility of successfully accomplishing de-carbonization goals.

These types of questions, however, are largely not being asked and current valuations of residential solar do not include the costs and benefits of transitioning to and accomplishing a de-carbonized electric sector. There appears to be very few people, if any, considering these types of questions. These types of longer-term cost-benefits questions to the de-carbonization goal are largely conceptual right now, according to a solar power industry representative (Solar energy industry representative 2016). Some states like Minnesota are having deep-dive electric-engineering technical conversations, but they appear to revolve more around ensuring technical feasibility of the electric system with higher intermittent source levels and not necessarily addressing the value of residential solar in the de-carbonization process (Minnesota energy regulator 2016). Utilities largely remain reactionary to regularity directives and strong customer demands, only doing what they need to do when they need to do it to remain compliant. There needs to be a proactive look at the long-term ramifications of increased solar PV on the grid so utilities are better situated to comply with policy and social goals.

Conclusion

Residential solar installations are booming across the country. The boom has been caused by growing competitiveness in the solar industry, generous residential solar policies, and growing customer preferences. The growth of residential solar has created many questions for the electric sector. These questions range from what are the costs and benefits of residential solar systems in the operational capabilities of the electric grid, to how to value the solar electricity generated from those PV systems and what that value should be. With the electric sector facing regulations and societal pressure to de-carbonize, there appears to be an obvious information gap in evaluating what residential solar role can and should be in accomplishing de-carbonization goals.

Residential solar PV is already providing de-carbonization benefits to the electric sector and should continue to play a role in de-carbonization contributions, especially as a value on these resources remains in limbo and there doesn't appear to be any significant reason that already deployed and invested in resources would be hampering de-carbonization efforts. A better understanding and methodology of establishing the costs and benefits residential solar resources bring to utilities, customers, and society is necessary to accurately value these resources and for deployment trajectory to follow that value. While it's clear many costs and benefits of residential solar on an electric system are known, the lack of consensus on the value of those costs and benefits is surprising.

It's also important to recognize that residential solar systems don't work as one unit, and they provide electricity and interact with the electric grid in new ways. As our electric sector grows more renewable and more intermittent, new challenges will arise. The generation resources deployed today and into the foreseeable future will affect how the electric grid operates. With residential solar increasingly being a generation source, how that source interacts with other generating sources and the electric grid in the future is critical, not just for system operations and reliability, but in order to more strategically deploy generation resources that together provide the best de-carbonization opportunities. The gap of knowledge about future grid operations with an increasing residential solar penetration is stark. Investment and support now in specific generation resources could significantly save or cost a utility future financial and operational resources in meeting de-carbonization goals. The gap of knowledge on long-term implications must be addressed for a better understanding of how de-carbonization goals can and should be met. Until then there appears little reason for residential solar not to play a robust future role in the de-carbonization of the electric sector, and integration challenges will be left up to the electric sector along the way.

This analysis points to the gaps in understanding the scope of implications of residential solar on the electric system. In recognizing these gaps, this analysis also serves as a call for additional and more comprehensive studies and testing on how residential solar resources interact with an increasingly more variable electric system. A better understanding of those interactions now will allow for a potentially more efficient path toward the de-carbonization of the electric sector. It will also serve in better understanding the total value of those resources toward de-carbonization efforts to ensure the resource value is being accurately reflected in public policy decisions. While concerns from utilities and grid operators are real about system operations, they appear solvable technical challenges that follow with the evolution of the electric sector. These challenges do not appear to serve as cause to change the current trajectory of residential solar nor hamper its potential to aid in meeting the policy and societal goals of de-carbonizing the U.S. electric sector.

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