ASSESSING THE BENEFITS OF DISTRIBUTED SOLAR IN VIRGINIA

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L. Douglas Wilder School of
Government and Public Affairs
Center for Urban and Regional Analysis

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1. Research Background

In the Fall of 2019, the Maryland-DC-Delaware-Virginia Solar Energy Industries Association (MDV-SEIA) asked the Center for Urban and Regional Analysis (CURA) at Virginia Commonwealth University to evaluate the impacts of the potential purchase, installation, and maintenance of 2,500 MW of new distributed solar photovoltaic (PV) generation capacity in Virginia, addressing the following specific outcomes:

- The estimated contributions to the Virginia economy, including direct, indirect, and induced impacts;
- The potential impacts on consumer electricity rates; and
- The anticipated reductions in greenhouse gases (i.e., carbon dioxide) and other air pollution emissions

This report summarizes the findings of the study, organized into three different sections. Section 2 uses an input-output economic model to detail the economic benefits generated by the distributed solar industry in Virginia, both in its current state and with the proposed addition of 2,500 MW of new generation capacity. Section 3 summarizes recent research on the electric grid's capacity to support distributed solar, the "value" of distributed solar energy to electric utilities, and the impact that increased distributed solar generation could have on retail electricity rates. Finally, Section 4 quantifies the amount of electricity that would be produced by the proposed new distributed solar capacity and the resulting reductions in greenhouse gas (GHG) and air pollution emissions.

1.1. Definition of Terms and Modeling Assumptions

Solar PV systems are measured by their installed power-generating capacity, in kilowatts (kW) or megawatts (MW). One kW is equal to 1000 watts, and one MW is equal to 1,000,000 watts, or 1,000 kW. The number of watts refers to how much electric power the system can produce at a single moment, under ideal conditions. When solar PV systems generate power for a period of time they produce electrical energy, i.e., electricity, measured in kilowatt-hours (kWh) or megawatt-hours (MWh). For example, a 10 kW system receiving full direct sunlight for two hours would produce 20 kWh of electricity (10 kW times two hours), not counting system losses and conversions (i.e., "de-rating," discussed further in section 3).

Solar PV systems come in a variety of sizes, but are typically lumped into three categories based on both generating capacity and location. The largest, "utility-scale" PV systems have a capacity of between a few dozen to upwards of hundreds of MW, and typically take the form of ground-mounted "solar farms." Mid-sized systems are typically referred to as "commercial" scale, in that they tend to serve commercial customers (e.g. shopping malls or other retail centers, factories or warehouses, government or educational buildings, etc.). The smallest systems are "residential" scale, located on individual homes, with a generation capacity of around 4-8 kW on average. Residential and commercial-scale systems are often located on building rooftops, but they can also be ground-mounted elsewhere on residential or commercial properties. Taken together, these two smaller categories are known as "distributed" solar PV systems. For this study we also included "shared solar'" installations, also known as "community solar" in markets outside of Virginia, as a form of new distributed solar capacity. Shared solar allows customers who cannot have their own on-site solar (e.g., renters, low-income households, etc.) to subscribe to a portion of the electricity produced by an off-site solar installation.

Two key characteristics of distributed solar PV systems are that they are most often located "behind the meter," in that they provide power directly to one or more buildings, and that from those buildings they connect to the electrical distribution grid (the system of lower-voltage power lines that connects electricity customers). In Virginia, and most other states, electricity customers with behind-the-meter solar PV systems can return the excess electricity that their systems generate to the electrical distribution grid. They receive full retail rate credit on their electricity bill for each kWh returned to the grid, through an arrangement known as "net-metering." Net metering has been a major driving force in the growth of distributed solar, as it allows system owners to receive benefits for the excess electricity generated during periods of high production, while also accessing electricity from the grid at times when their systems are not producing. Virginia law currently limits “net-metered” generation capacity to 1% of peak load (i.e., peak electric power demand) within each electric utility service area.

This study models the impacts of adding 2,500 MW of new distributed solar capacity in Virginia, consistent with MDV-SEIA’s policy goals, divided into sub-totals for residential, small commercial, large commercial, and shared solar installations. The model includes an average installed price for each system type in Virginia in 2020, shown in Table 1 below, as reported by MDV-SEIA members. The resulting weighted average installation price of $2.415 per watt was used in the modeling of potential economic impacts from new distributed solar PV in Virginia.

Table 1. Modeling Assumptions

System Type	Total Installed Capacity (MW)	Average Installed Price ($/watt)
Residential	500	$3.30
Small Commercial	750	$2.55
Large Commercial	750	$2.00
Shared / Community	500	$1.95
Total	2,500	$2.415*

Note: This weighted average price is produced by multiplying the installed capacity for each system type by their respective average prices, then dividing the resulting total by 2,500.

1.2. Current State of Distributed Solar Energy in Virginia

Virginia has seen rapid growth in utility-scale solar, which went from zero installations at the beginning of 2016 to 413.7 MW of capacity by October 2019, according to the U.S. Energy Information Administration. Distributed PV has also increased, from just over 5 MW in 2011 to 92 MW by October 2019, but the state still ranks only 29th in total distributed solar PV capacity. Only 18% of Virginia’s solar PV capacity is from distributed systems, compared to 41% nation-wide, which puts Virginia 42nd among all states in that regard.[1] Incorporating data from the U.S. Census Bureau, we calculate that Virginia is 36th among all states in distributed solar PV capacity per-capita.[2]

Prior research by the U.S. National Renewable Energy Laboratory (NREL) demonstrates that Virginia has the potential to expand its distributed solar capacity to far beyond current levels. A 2016 NREL report found that Virginia’s buildings could support up to 28,500 MW of distributed solar PV systems.[3] Another NREL study from 2012 estimated that Virginia had the technical potential (based on “renewable resource availability and quality, technical system performance, topographic limitations, environmental, and land-use constraints only”) to support 19 GW (19,000 MW) of rooftop solar PV, which would produce over 22,000 GWh (over 22 million MWh) of electricity.[4] This represents more than 200 times the state’s current distributed solar capacity and 19% of total statewide electricity demand as of 2018. In other words, the technical potential for distributed solar energy in VA, per the 2012 NREL report, is roughly eight times that modeled in this study.

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[1] U.S. Energy Information Administration. (2019b). *Electric Power Monthly with Data for October 2019. Table 6.2.B. Net Summer Capacity Using Primarily Renewable Energy Sources and by State*. http://www.eia.gov/electricity/monthly/

[2] U.S. Census Bureau. *2013-2017 American Community Survey 5-Year Estimates*. https://factfinder.census.gov

[3] Gagnon, P., *et al.*, National Renewable Energy Laboratory. (2016). *Rooftop solar photovoltaic technical potential in the United States: A detailed assessment*. http://www.nrel.gov/docs/fy16osti/65298.pdf

[4] Lopez, A., *et al.*, National Renewable Energy Laboratory. (2012). *U.S. renewable energy technical potentials: A GIS-based analysis*. http://www.nrel.gov/docs/fy12osti/51946.pdf

2. Estimated Economic Impacts of the Distributed Solar Industry in Virginia

2.1. The Basics of Economic Impact Analysis

Economic activities—that is, spending or investing money—have impacts that reverberate throughout the economy to different industries. Each dollar spent upgrading a manufacturing facility, purchasing raw materials, or installing and operating a solar panel is distributed to interconnected industries through backward linkages. Put more simply, industries purchase goods and services from other industries, and increased or decreased spending in one industry has impacts on other industries that can be modeled. This modelling is called Input-Output Modeling, and IMPLAN—an economic modeling program—allows us to customize models to account for project specifics and regional industrial spending patterns.

For this analysis we have modeled the economic impact of the distributed solar industry in Virginia under two scenarios: the current level of economic impact, based on the number of workers now employed in the distributed energy sector, and the potential economic impact based on an investment in 2,500 MW of new distributed solar generation capacity. For each scenario the modeling incorporates three levels of economic impact:

- **Direct impact** refers to the initial spending distribution or expenditures of the immediate investment. For example, the total investment in installing and operating/maintaining commercial and residential solar panels goes towards the purchase of equipment and construction supplies and services (intermediate expenditures) and construction workers (labor income). This initial round of spending creates ripple effects (also known as “multiplier effects”) within the state as those dollars move through the economy. The intermediate expenditures become inputs for supplier industries, and a portion of labor income is put back into the economy as household spending. These additional effects are described as indirect and induced impacts.
- **Indirect impact** refers to “supplier” effects, or the inter-industry spending through backward linkages that track industry purchases backward through the supply chain. Suppliers who receive money through the intermediate expenditures of the original investment must also buy additional goods and services to accommodate new demand. For example, construction suppliers may need to purchase raw materials, and engineering firms must purchase CAD software licenses. As purchases are made from other firms in Virginia, the state economy is stimulated further.
- **Induced impact** looks at changes in household spending, outside the supply chain of the industry that is being analyzed. These are the effects of employees spending their wages. Companies that receive additional demand as a result of direct and indirect effects must meet that demand with increased labor—additional workers, hours, wages, or some combination of the three. This results in new or additional employee income, some of which will go towards goods and services in the area. Induced impacts refer to this additional spending within Virginia.[5]

Direct, indirect, and induced impacts are three stages in the flow of money through the economy. At each of these stages we can estimate how much of the total output will be in the form of value added, labor income, and supported jobs.

Finally, spending that goes towards suppliers or goods and services in Virginia will impact the state economy. However, sometimes money goes towards materials, goods, or services outside the area due to a lack of supply or general purchasing patterns. Leakages occur at every stage of the economic cycle, from production to final demand, through imports (goods purchased outside the area), taxes, corporate profits, in-commuters, and savings. These items represent money that will not cycle through the local economy, and therefore will not be

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[5] Day, Frances, (2012). “Principles of Impact Analysis and IMPLAN Applications.” Minnesota IMPLAN Group, Stillwater, MN.

included in the model. Because of the limited presence of manufacturing businesses for solar panels or solar energy system components in Virginia, this study assumes that spending for the manufacturing and purchase of those materials is a net leakage outside the state economy.

2.2. Estimating the Current Economic Impacts of Distributed Solar Energy in Virginia

A 2018 report by The Solar Foundation found that there are 3,890 jobs in the solar energy industry in Virginia, of which 2,903 are installation jobs.[6] Nationally, The Solar Foundation reports that 86% of all solar installation jobs are in the distributed solar sector, as residential and commercial-scale installations are more labor-intensive than utility-scale solar.[7] Absent any data on the breakdown of installation jobs by installation type in Virginia, we applied the national 86% figure to the total number of installation jobs in the state, which translates to an estimated 2,497 distributed solar installation jobs in Virginia.

The 2018 Solar Foundation report also identified 288 solar manufacturing jobs, plus about 700 jobs in wholesale trade and distribution, operations and maintenance, and other job types (e.g., administrative services). Given the small overall magnitude of distributed solar capacity in Virginia, compared to utility-scale, we credited the distributed sector with smaller percentages of the employment in the manufacturing, wholesale trade, and "other" sectors. We did not attribute any manufacturing jobs to distributed solar, and reduced the number of wholesale trade and other jobs attributed to distributed solar to about 42% of the statewide jobs in those sectors. This resulted in an estimated total direct employment of 2,892 jobs credited to distributed solar energy in Virginia, as shown in Table 2.

Table 2. Estimated Distributed Solar Employment by Job Type in Virginia

Job Type	**Total VA Solar Employment**	**Estimated Distributed Solar Employment in VA**
Installation	2,903	2,497
Manufacturing	288	0
Wholesale Trade & Distribution	280	120
Operations & Maintenance	223	192
Administrative / Other	196	83
Total	*3,890*	*2,892*

Source: Solar Foundation (2018) for total VA solar employment, with additional assumptions and calculations by authors.

Using this level of current employment as the direct input for our modeling, we estimate that the current distributed solar industry in Virginia generates nearly $185 million in labor income and $445 million in total direct economic output per year. Those direct expenditures have associated indirect and induced impacts, which together support approximately 1,800 additional jobs, $95 million in additional labor income, and $262 million in additional total economic impact. Taken together, the direct, indirect, and induced impacts of the current distributed solar industry produce nearly 4,700 jobs, with a combined $280 million in labor income (distributed wages), and a total economic benefit of $727 million, as shown in Table 3 below.

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[6] The Solar Foundation (2018b). *Solar Jobs Census 2018: Virginia*. https://www.thesolarfoundation.org/solar-jobs-census/factsheet-2018-va/

[7] The Solar Foundation (2018a). *National Solar Jobs Census*. https://www.thesolarfoundation.org/national/

Table 3. Estimated Current Economic Impacts of the Distributed Solar Industry in Virginia (<100 MW)

Type of Impact	Employment	Labor Income	Total Economic Impact
Direct	2,892	$184,592,222	$444,699,618
Indirect	699	$43,812,197	$122,397,450
Induced	1,080	$51,083,115	$159,721,077
Total	*4,671*	$279,487,534	*$726,818,145*

In addition, we estimate that this total economic impact would generate about $59.5 million in federal tax revenue and $28.6 million in state and local revenue.

2.3. Estimating the Potential Economic Impacts of Distributed Solar Energy in Virginia

To estimate the potential economic impact of 2,500 MW of new distributed solar energy in Virginia, we used the average cost per watt ($2.415) to calculate total direct spending, and used that number as the input into the economic input-output model. This weighted average cost per watt includes the cost of manufacturing, purchase and distribution, installation, and related administrative services. On the surface, this would translate into a total direct investment of a little more than $6 billion.

However, as mentioned in section 2.1, not all this spending would happen in Virginia. In particular, after consulting with MDV-SEIA representatives and field experts, CURA researchers considered all the spending for manufacturing, and some of the spending for the purchase of solar panels and equipment, to be a net leakage outside the state economy. These leakages reduce the total initial investment by 25%, to $4.53 billion.

Based on this initial spending, we estimate that expanding Virginia's distributed solar capacity to 2,500 MW would increase the number of directly supported jobs to more than 29,000, which translates into almost $2 billion in labor income and $4.34 billion in direct impact.[8] This expanded investment in distributed solar would lead to over 17,000 more indirect and induced jobs, resulting in an additional $930 million in labor income and $2.8 billion in total indirect and induced economic impact.

Taken together, the direct, indirect, and induced impacts of this potential expanded distributed solar industry would produce over 47,000 jobs, with a combined $2.85 billion in labor income, and a total economic benefit of $7.1 billion, as shown in Table 4 below.

Table 4. Potential Economic Impacts of 2,500 MW of New Distributed Solar Energy in Virginia

Type of Impact	Employment	Labor Income	Total Economic Impact
Direct	29,462	$1,921,187,837	$4,341,346,441
Indirect	6,575	$411,230,740	$1,153,798,663
Induced	11,031	$521,660,748	$1,631,050,170
Total	47,068	$2,854,079,325	$7,126,195,274

In addition, this new economic activity would generate over $860 million in federal, state, and local tax revenues.

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[8] Some of the initial spending does not translate into a direct impact. Spending for the purchase of solar panels and related equipment gets divided in production costs + margins (transportation, retail, etc.). Considering the main assumption that solar panel production is mainly happening out of state, the only margin that the system is considering in this particular case is the margin applied by the wholesale trading businesses (wholesale margin).

3. Evaluating the Potential Impacts of New Distributed Solar Capacity on Electricity Rates

Some critics allege that distributed solar development imposes costs on electric utilities, which they argue must naturally be passed on to regular utility customers, a phenomenon they label as "cross-subsidization." There is no evidence to suggest that this is occurring in Virginia, or would occur if a significantly higher amount of distributed solar were installed across the Commonwealth.

In order for "cross-subsidization" to occur, each of the following would have to take place:

1. The energy produced by distributed solar facilities would have to be valued at less than the retail rate of electricity;
2. The market penetration of distributed solar would have to be sufficient enough that these incremental losses add up to significant measurable costs to electric utilities; and
3. Electric utilities would have to receive State Corporation Commission approval to raise customer rates, after a full base rate case review, based on these demonstrated losses.

On the first point, many states have conducted "value of solar" studies to determine whether the electricity produced by distributed solar customers has a net-positive or net-negative financial benefit for electric utilities. A report by the Lawrence Berkeley National Laboratory (LBNL) evaluated 19 such studies, to compare the resulting value of solar calculations to the cost of electricity service (i.e., the retail rate) for the respective state or utility. Their results varied widely, with the value of solar ranging from less than 33% to more than 200% of the respective retail rates.[9]

However, further analysis of the studies included in the LBNL report shows that those studies that found a net-negative value of solar were primarily sponsored by electric utilities. The studies conducted for public utility commissions or other independent agencies all found a neutral or net-positive value of solar, when accounting for all "core" benefits to ratepayers and utilities, even when broader societal benefits from carbon reduction, job creation, etc. are excluded. The results from those studies are summarized in Table 5 below.

Table 5. Results of Recent Value of Solar Studies conducted for Public Utility Commissions

State / Region	Year	"Core" Value of Solar (cents/ kWh)	Ratio of Core VOS to Retail Electric Rate
Maine	2015	24.3	185%
Mississippi	2014	17.4	176%
PJM Region	2012	17.6	121%
California	2013	14.6	98%
Nevada	2014	13.1	134%
Vermont	2014	24.4	163%

Source: Barbose, 2017. Note these "core" VOS values include avoided costs for utilities and other ratepayer benefits.

The fact that the "core" value of solar rates shown in Table 5 do not include economic impacts is notable, as including those benefits would greatly increase the value of solar.

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[9] Barbose, G. (2017). Lawrence Berkeley National Laboratory. *Putting the Potential Rate Impacts of Distributed Solar into Context*. https://emp.lbl.gov/publications/putting-potential-rate-impacts

While no comprehensive value of solar study has been conducted in Virginia, the prior studies from public utility commissions and other independent agencies indicate that the value of distributed solar in the Commonwealth is likely roughly equal to, or slightly above, the retail rate. However, even if the value were found to be below the retail rate, the theoretical impact on ratepayers would be miniscule.

The LBNL study developed a method to estimate these theoretical rate impacts, based on the value of solar, the retail electricity rate, the rate of compensation paid to distributed solar owners, and the market penetration of distributed solar in a given service area. For example, assuming a full net-metering program for distributed solar customers, the LBNL formula shows that if the value of solar were only 80% of the retail rate, and market penetration were 2%, the theoretical increase in electricity rates would be 0.4%.

Putting this in context, distributed solar currently has a market share of about 0.3% in Virginia (92 MW of distributed solar compared to 34,581 MW[10] of total electric power generating capacity), and the average residential customer pays a monthly electricity bill of around $135.[11] Under a very conservative scenario, in which the value of solar were only 80% of the retail rate, increasing the market penetration ten-fold (to 3%) would in theory raise the average Virginia residential customer's bill by only about 80 cents a month. With these same conservative assumptions, increasing the market penetration to 5% would raise the average residential customer's bill by about $1.35 a month (i.e., a 1% rate increase).

It is important to reiterate that these theoretical bill increases are based on a scenario where the value of solar is less than the retail rate. For this "cross-subsidization" to actually occur, utilities would have to get approval from the State Corporation Commission to raise rates, based on hard evidence that the growth of distributed solar is in fact costing them money. However, the prior studies conducted for public utility commissions in other states indicate that the value of solar is more likely to be above the retail rate, creating a net-positive economic benefit for utilities. If anything, a full accounting of the impacts of distributed solar on utilities would likely support an argument for reducing electricity rates for consumers, not increasing them.

A related argument against distributed solar is that it will require utilities to upgrade their electrical distribution grids. This concern is based on the fact that net-metered solar systems release electricity onto a distribution grid that was not built to handle such bi-directional power flows.[12] However, the installation of new distributed solar capacity can also have benefits for the distribution grid, such as reducing line losses and helping utilities avoid the cost of new distribution infrastructure.[13]

The question then becomes, how much distributed solar can the electric grid handle? Prior studies indicate that most distribution service areas can easily host at least 5% distributed solar penetration, if not much higher.[14, 15] For Virginia, the previously mentioned NREL study from 2012 estimated that the state had the technical potential to support 19 GW (19,000 MW) of rooftop solar PV. This would be enough to produce over 22,000

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[10] U.S. Environmental Protection Agency (2016). *Emissions & Generation Resource Integrated Database (eGRID).* https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid.

[11] U.S. Energy Information Administration (2019a). *2018 Average Monthly Bill- Residential.* https://www.eia.gov/electricity/sales_revenue_price/pdf/table5_a.pdf

[12] St. John, J. (2013). *How much renewable energy can the grid handle?* http://www.greentechmedia.com/articles/read/on-the-uncertain-edge-of-the-renewable-powered-grid

[13] Perez, R., et al. (2012). *The value of distributed solar electric generation to New Jersey and Pennsylvania*. https://www.nj.gov/emp/pdf/cleanrenewablepower/MSEIA-Final-Benefits-of-Solar-Report-2012-11-01(1).pdf

[14] GE Energy. (2010). *Western wind and solar integration study*. www.nrel.gov/docs/fy10osti/47434.pdf

[15] Hering, G. (2015). *Solar's new home on the grid: New tools and methods work to integrate solar on local circuits*. eprijournal.com/wp-content/uploads/2015/07/Solars-New-Home.pdf

GWh (over 22 million MWh) of electricity,[16] which corresponds to about 19% of annual statewide electricity demand (118 million MWh in 2018).[17]

At the regional level, a report for PJM Interconnection found that, with sufficient grid investments, the region could receive up to 30% of its electricity supply (in MWh) from wind and solar generation, without incurring any significant operating issues and resulting in reduced wholesale electricity prices. This included a scenario in which nearly 34,000 MW of distributed solar were added to the PJM grid,[18] which is equal to roughly 20-25% of the summer peak load for the PJM region (153,000 MW in 2017).[19]

In addition, a study performed in 2016 by Navigant Consulting for Dominion Energy showed that the utility's distribution lines can, on average, handle massive increases in distributed solar capacity without the need for costly upgrades. The study looked at a subset of over 1,500 distribution "feeders," out of 1,800 in the Dominion system, and divided them into 14 clusters, based on similar characteristics (voltage, load, number of customers, etc.). They then identified the "representative" feeder that was most similar to the average characteristics for each cluster, and ran a simulation model that determined the distributed solar "hosting capacity" for each representative feeder. While the hosting capacity of those 14 representative feeders varied greatly, they could together support over 200 MW of distributed solar, as summarized in Table 6.[20]

Table 6. Results of Navigant Consulting Simulation of Distribution Feeder Solar Capacity in Dominion Territory

Cluster	Number of Feeders in Cluster	Distributed Solar Hosting Capacity (MW) of Representative Feeders	Cluster	Number of Feeders in Cluster	Distributed Solar Hosting Capacity (MW) of Representative Feeders
1	171	30	8	21	0
2	358	3	9	52	15
3	100	30	10	96	22
4	76	0	11	81	7
5	53	11	12	140	11
6	38	15	13	184	22
7	156	22	14	31	15
Totals				**1557**	**203**

Source: Navigant Consulting, 2016. Data from Tables 3-4 (p. 18) and 3-8 (p. 31).

In other words, those 14 "representative" feeders alone could support more than double the current statewide capacity. Extrapolating the results for those feeders to the rest of the Dominion system would suggest that a massive expansion of distributed solar capacity can be supported, if located properly on the distribution grid.

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[16] U.S. Energy Information Administration. (2019d). *Table 2.8. Sales of Electricity to Ultimate Customers by End-Use Sector*. https://www.eia.gov/electricity/annual/html/epa_02_08.html

[17] Lopez, A., *et al.*, National Renewable Energy Laboratory. (2012). *U.S. renewable energy technical potentials: A GIS-based analysis*. http://www.nrel.gov/docs/fy12osti/51946.pdf

[18] GE Energy. (2014b). *PJM renewable integration study – Executive Summary*. http://www.pjm.com/-/media/committees-groups/subcommittees/irs/postings/pris-executive-summary.ashx?la=en

[19] PJM. (2017). Virginia State Report. https://www2.pjm.com/-/media/library/reports-notices/state-specific-reports/2016/2016-virginia-state-report.ashx?la=en

[20] Navigant Consulting. (2016). *Virginia Solar Pathways Project: Study 1: Distributed Solar Generation Integration and Best Practices Review.* http://solarmarketpathways.org/wp-content/uploads/2017/09/DVP_DG-Transmission-and-Distribution-Grid-Integration-Study-1.pdf

4. Calculating Potential Greenhouse Gas and Air Pollution Savings from Distributed Solar

The environmental and public health benefits of solar energy are well-documented. The most obvious of these come from the potential for solar power to displace electricity production from fossil-fuel power plants, thus off-setting or “mitigating” the direct air pollution (e.g., nitrous oxides and particulate matter) and green-house gas (GHG) emissions that would have otherwise been released from burning those fossil fuels. But how much pollution mitigation can we actually get from distributed solar? The answer depends on two factors: the amount of electricity produced by distributed solar and the emissions rate of the conventional electricity displaced.

The amount of electricity produced by a distributed solar installation is based on three factors: its “installed capacity” (in kW or MW) of potential power generation (a function of system size and conversion efficiency), the average amount of sunlight or “solar insolation” it receives at its location, and the “de-rating” or power loss associated with the system (usually around 15%). If we were to install 2,500 MW of distributed solar capacity in Virginia, then those systems would produce somewhere between 3.40 and 3.75 million MWh of electricity per year, as indicated by the data sources identified in Table 7. This would equal about 3% of annual statewide electricity use (118 million MWh in 2018),[21] and would be enough to power up to 125,000 homes (at an average of 25,000 – 30,000 kWh per year).

Table 7. Estimated Electricity Generation from 2,500 MW of Distributed Solar in Virginia

Method	**Estimated Generation (MWh/yr)**
Energy for Sustainability[22]	3,723,000[a]
EPA AVERT[23]	3,602,780[b]
GridPIQ[24]	3,520,469[c]
NREL Annual Technology Baseline (ATB)[25]	3,740,034[d]
NREL PV Watts[26]	3,408,333[e]

[a] *Assumes 4.8 kWh / m^2 / day average annual insolation and 15% de-rating factor*

[b] *Based on U.S. EPA’s AVoided Emissions and geneRation Tool (AVERT); assumes 2,500 MW distributed solar input in SERC region*

[c] *Based on Pacific Northwest National Laboratory Grid Project Impact Quantification tool; assumes 2,500 MW distributed solar input in SERC region in Lynchburg (average 5.0 kWh / m^2 / day average annual insolation) and 13.4% de-rating factor*

[d] *Extrapolated from ATB “standard scenario results” mid-case scenario estimate of 48,411 MWh of electricity produced in from 32.36 MW of installed distributed solar capacity in Virginia in 2018*

[e] *Extrapolated from PV Watts estimates for rooftop systems at 12 sites dispersed geographically across Virginia, with average annual solar insolation values between 4.76 and 5.19 kWh / m^2 / day and a 13.5% de-rating factor*

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[21] U.S. Energy Information Administration. (2019d). *Table 2.8. Sales of Electricity to Ultimate Customers by End-Use Sector*. https://www.eia.gov/electricity/annual/html/epa_02_08.html

[22] Randolph, J., & Masters, G. (2008). Energy for Sustainability. Washington, DC: Island Press.

[23] U.S. Environmental Protection Agency. (2019b). *AVoided Emissions and geneRation Tool (AVERT)*. https://www.epa.gov/statelocalenergy/avert-web-edition.

[24] Lawrence Berkeley National Laboratory. (2019). Grid Project Impact Quantification. https://gridpiq.pnnl.gov/app/#!/

[25] National Renewable Energy Laboratory. (2019a). *2019 Annual Technology Baseline*. https://atb.nrel.gov/electricity/2019.

[26] National Renewable Energy Laboratory. (2019b). *PVWatts Calculator*. https://pvwatts.nrel.gov/pvwatts.php.

The conventional method of estimating GHG emission reductions from renewable energy or energy efficiency improvements in a given area is to simply determine the total MWh of electricity that those improvements generate or conserve (i.e., the amount of conventionally produced electricity that would be offset), and multiply that total by the average rate of CO_2 or CO_2-equivalent GHG emissions per MWh of electricity consumed in that location.

The most robust source of emissions rate information is the U.S. Environmental Protection Agency's Emissions & Generation Resource Integrated Database (eGRID), which includes information on electricity generation, fuel consumption, direct air pollution, and GHG emissions from the national level all the way down to the scale of individual power plants. The most recent eGRID database from 2016[27] lists the total electric power generating capacity in Virginia at 34,581 MW, which produced 92.6 million MWh of electricity and generated 37.7 million tons of CO_2 emissions, for a rate of 0.407 tons of CO_2 emissions per MWh.

However, our electricity infrastructure is neither built nor managed in a way that falls within state boundaries. Therefore, a more accurate method of calculating emissions reductions is to use an emissions rate that corresponds to the ways that the grid is managed. Most of Virginia falls within the boundaries of the Southeast Reliability Corporation (SERC), an entity that is charged by the Federal Energy Regulatory Commission with ensuring the reliability and security of the electric grid within the southeastern region.[28] The eGRID database breaks the SERC territory down further, with most of Virginia included in the Virginia-Carolina (SRVC) sub-region. The eGRID also includes data specific to the PJM, a regional transmission organization (RTO) that coordinates the wholesale electricity market across much of the Midwest and Mid-Atlantic, including almost all of Virginia.[29]

If Virginia were to install 2,500 MW of distributed solar, producing upwards of 3.75 million MWh of carbon-free electricity, this would mitigate between 1.51 and 1.94 million tons of CO_2 emissions, depending on the selected emissions rate as shown in Table 8 below.

Table 8. Estimated GHG Emissions Offsets, per Regional Average Emissions Rates

Method	**PJM Territory**	**SERC Region** [b]	**SRVC Sub-Region**
CO_2 emissions rate (lb/MWh)	957	1,035	805
CO_2 emissions rate (tons/MWh)	0.479	0.518	0.403
Total GHG offset (tons CO_2) [a]	1,794,874	1,940,689	1,509,909

[a] *Based on 2,500 MW of distributed solar generating an estimated 3.75 million MWh of electricity per year*

[b] *The SRVC sub-region has a lower emissions rate than SERC or PJM due to its higher levels of nuclear power generation*

However, the basic conversion rates shown above drastically underestimate the actual potential for distributed solar to displace GHG emissions, because they do not take into account the fact that solar energy production is exclusively during the daytime, when electricity demand is higher, more fossil-fuel power plants are running, and emissions rates are therefore elevated.

Figure 1 below shows that carbon emissions from electric power production in the SERC region vary throughout the day and by season. In all but the winter months, carbon emissions peak in the middle of the day, with the

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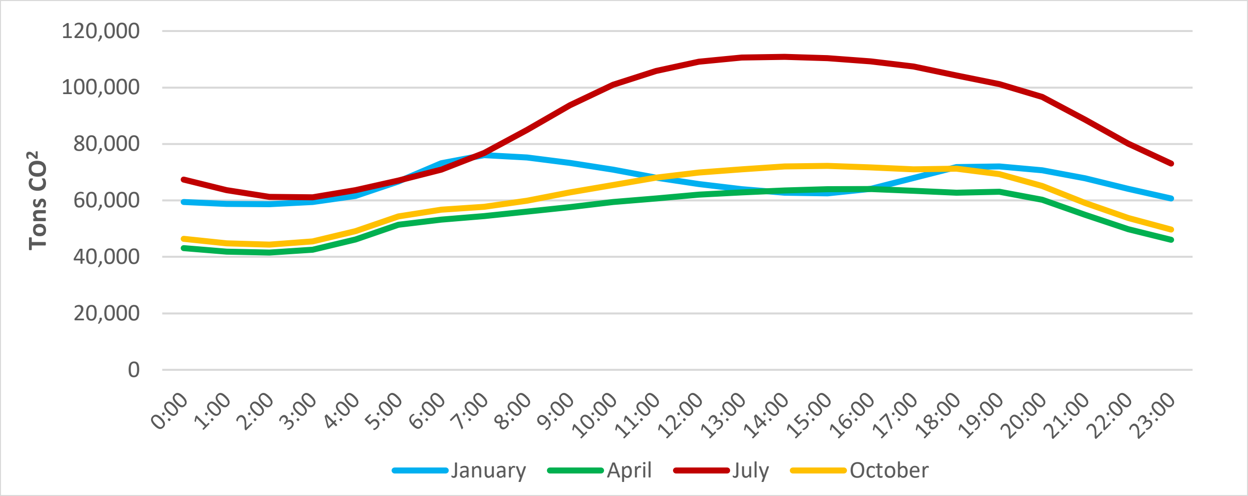
[27] U.S. Environmental Protection Agency. (2016). Emissions & Generation Resource Integrated Database (eGRID). https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid.

[28] Southeast Reliability Corporation. (2019). About SERC. https://www.serc1.org/about-serc.

[29] PJM. (2019). About PJM. https://www.pjm.com/about-pjm.aspx

highest emissions occurring in the summer months due to air conditioning loads. In the winter months emissions from power production peak in the morning and evening, as driven by home heating demand. These hourly emissions curves are similar for other types of air pollution from electric power production (sulfur dioxide, particulate matter, etc.).

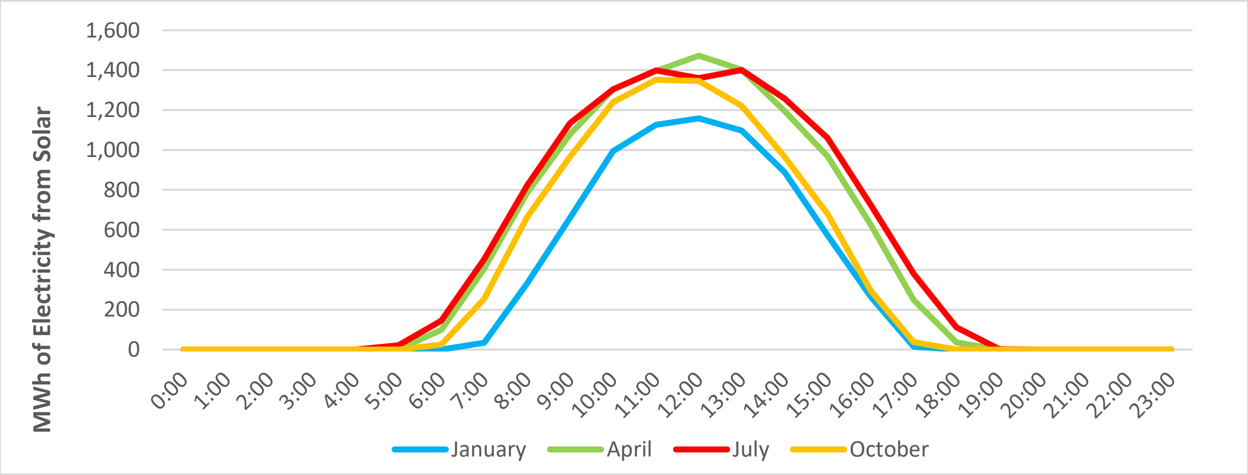
Figure 1. Average Hourly Weekday CO² Emissions from Electric Power Production, SERC Region



Source: Lawrence Berkeley National Laboratory (2019). Grid Project Impact Quantification (GridPIQ). https://gridpiq.pnnl.gov/app/#!/. GridPIQ uses U.S. EPA's AVoided Emissions and geneRation Tool (AVERT) and eGrid 2016 database for baseline generation and emissions data. Additional calculations by authors.

Figure 2 demonstrates that the electricity production from distributed solar energy peaks in the middle of the day. Comparing Figures 1 and 2 demonstrates that distributed solar energy production generally corresponds to the times when CO_2 emissions from conventional power generation are around their highest point. The only exception is during the winter months, when solar energy production is lower overall.

Figure 2. Average Hourly Electricity Generation from 2,500 MW of Distributed Solar in Virginia



Source: Lawrence Berkeley National Laboratory (2019). Grid Project Impact Quantification (GridPIQ). https://gridpiq.pnnl.gov/app/#!/. GridPIQ uses NREL System Advisor Model (SAM) for PV performance estimates.

This correspondence between peak solar energy production and peak emissions from conventional power generation demonstrates how using average emissions rates, such as those listed in Table 8 above, undersells the potential for solar energy to offset GHG emissions and other air pollution.

Therefore, a better method is to calculate the emissions reduction benefits of solar energy by taking into account the hour-by-hour electricity production and corresponding hourly emissions rates from conventional power. This research utilized two existing models to conduct this analysis: the U.S. EPA's AVoided Emissions and geneRation Tool (AVERT) and the Pacific Northwest National Laboratory's Grid Project Impact Quantification (Grid PIC) tool.

The AVERT tool models the outcomes of proposed energy efficiency and/or renewable energy investments by simulating the impact they would have on hour-by-hour electricity generation and resulting air pollution emissions at the regional level. Using granular data from the EPA's National Emissions Inventory and other sources, it employs advanced statistical analysis to model how individual power plants would respond to marginal system-wide load reductions, such as from the introduction of new distributed solar generation. It then scales those individual power plant responses back up to the regional level, thus estimating the air pollution savings from distributed solar or other clean energy improvements in a way that takes into account the complexities of regional grid operations and the hour-by-hour variations in electricity generation and emissions.

According to the EPA, the AVERT tool was developed via extensive peer review, beta-testing, and benchmarking against other similar systems, including those used by the electricity industry. It can be used to model a variety of different scenarios and has been cited by nearly 100 peer-reviewed academic research papers, government reports, and other analyses. It is available in a web-tool format or as an Excel template downloadable from the EPA website.[30] The Pacific Northwest National Laboratory's (Grid PIC) tool is a similar web-based application for estimating the emissions reductions and fuel cost savings from various types of clean energy improvements.[31] It uses the AVERT tool and the eGrid 2016 database for baseline generation and emissions data and the NREL System Advisor Model (SAM)[32] for PV performance estimates.

By taking into account the complexities of regional grid operations and the hour-by-hour variations in electricity generation and emissions, the AVERT and Grid PIC tools demonstrate that the avoided GHG emissions from distributed solar are much higher than would be estimated by relying simply on average emissions rates.

Table 9. Detailed CO_2 Emissions Offset Calculations from 2,500 MW of Distributed Solar in Virginia

Method	Estimated Generation	Mitigation Rate	Annual Emissions Offset
AVERT	3.60 million MWh/yr	0.699 tons CO^2 / MWh	2.52 million tons CO^2
GridPIQ	3.52 million MWh/yr	0.793 tons CO^2 / MWh	2.79 million tons CO^2

Using the average emissions rate for the SERC region produces an estimated GHG savings of around 1.94 million tons of CO_2 emissions. However, Table 9 above shows that the emissions reductions calculated using the more accurate AVERT and GridPIQ models are about 30-45% higher, at around 2.5 to 2.8 million tons of CO_2 respectively, even while using a slightly lower estimated electricity generation from the 2,500 MW of distributed solar capacity. To reiterate, these emissions figures reflect the impact that the new distributed solar in Virginia

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[30] U.S. Environmental Protection Agency. (2019a). *AVERT Overview and Step-by-Step Instructions*. https://www.epa.gov/sites/production/files/2019-05/documents/avert_overview_and_training_05-20-19_508.pdf.

[31] Pacific Northwest National Laboratory. (2019). *About GridPIQ*. https://gridpiq.pnnl.gov/doc/

[32] National Renewable Energy Laboratory. (2019c). *System Advisor Model (SAM).* https://sam.nrel.gov/.

would have on grid operations across the Southeast Reliability Corporation (SERC) region, which is the entity responsible for grid reliability and security for most of the southeastern U.S.

According to the U.S. Energy Information Administration, the CO_2 emissions from the electric power sector in Virginia was around 100 million metric tons, or around 110 million tons, in 2017.[33] Thus, the 2.5 to 2.8 million tons of CO_2 that could be mitigated by installing 2,500 MW of distributed solar capacity would reduce the state's annual electric power carbon footprint by about 2.5%.

To put this figure in perspective, 2.8 million tons of CO_2 is equal to the amount of GHGs emitted by nearly 540,000 cars (driving at the national average of 22.3 mpg for 11,484 miles per year), or the CO_2 emissions from burning over 285 million gallons of gasoline or 1.4 million tons of coal (enough to fill nearly 14,000 rail cars). Put another way, the same amount of CO_2 could be avoided by converting nearly 97 million incandescent light bulbs to LEDs, or could be sequestered by planting over 3.3 million acres of forest in a year.[34]

Finally, the AVERT model also provides data on the amount of direct air pollution emissions that would be mitigated, both across the SERC region and specifically in Virginia, as shown in Table 10.

Table 10. Direct Air Pollution Emissions Mitigated from 2,500 MW of Distributed Solar in Virginia

Location of Emissions	Sulfur Dioxide (SO_2)	Nitrous Oxides (NO_x)	Particulates (PM 2.5)
SERC Region	2,693,025 lbs / year	3,218,868 lbs / year	348,023 lbs / year
Virginia	167,495 lbs / year	308,326 lbs / year	18,817 lbs / year

Source: U.S. Environmental Protection Agency. (2019). AVoided Emissions and geneRation Tool (AVERT). *https://www.epa.gov/statelocalenergy/avert-web-edition.asdfd*

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[33] U.S. Energy Information Administration. (2019c). *State Carbon Dioxide Emissions Data*. https://www.eia.gov/environment/emissions/state/

[34] U.S. Environmental Protection Agency. (2019c). *Greenhouse Gas Equivalencies Calculator*. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator; https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references#lights

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