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Utility-Scale Solar in Virginia: An Analysis of Land Use and Development Trends

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Utility-Scale Solar in Virginia

An Analysis of Land Use And Development Trends

Utility-Scale Solar in Virginia: An Analysis of Land Use and Development Trends

A Capstone Professional Plan
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Top photo on cover page-aerial of Silicon Ranch Solar
taken by Green Power EMC

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Acknowledgments

I would like to thank all my friends, family colleagues, classmates, and professors that have allowed me to share ideas with them throughout this process. Your comments, questions, and suggestions have all influenced this research.

Dr. Pitt for helping me in the initial formulation of this research as well as your support and expertise throughout this process.

Dr. Suen for answering many of my GIS questions and taking the time to talk through my thought process during my work on this plan.

Dr. Verma for providing thoughtful insights and patience with all my questions and ideas.

Carrie Hearne and Mike Skiffington for allowing me to work and learn alongside you both.

Special thanks to all of the faculty members of the MURP program for your guidance and support throughout my graduate studies. Although I never imagined that my graduate studies would be conducted almost entirely from home, your willingness to adapt and reimagine the MURP program for virtual learning has made this an invaluable experience.

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Executive Summary

As of January 2021, Virginia has deployed more than 1,500 megawatts (MWac) of utility-scale solar generation capacity, with thousands of additional megawatts of generating capacity under construction and planned for development in the coming years. Continued growth is anticipated because of Virginia's aggressive renewable portfolio standards in addition to recent technological improvements and declining system costs. However, an emerging concern regarding the widespread development of utility-scale solar facilities is its potentially significant land use. While solar energy has become an important component of land use considerations in many rural communities across the Commonwealth, there is very little information available that comprehensively evaluates the existing land use impacts and development trends of solar facilities. This study investigates the spatial characteristics of existing utility-scale solar facilities in Virginia using GIS techniques.

Ultimately, the data and analysis provided in this study characterize the impacts of utility-scale solar facilities and clarify some of the uncertainties related to their recent development in Virginia. By quantifying and summarizing the characteristics of the areas impacted by solar facilities, this report provides a foundation for supporting the sustainable development of future solar energy facilities. Clearly understanding the existing conditions and trends of solar development in Virginia today will help to inform better land use practices tomorrow. Accordingly, this research provides recommendations for continuing to track the development of solar facilities across the state in the coming years. It also considers policies that promote efficient land use to maximize the benefits of solar energy development while also mitigating potential impacts.

Figure 1. *Briel Solar Facility, Henrico County, VA*

(Photo taken by Aaron Berryhill)

1.0 | Introduction

As Virginia becomes increasingly dependent on renewable energy, solar energy will be an essential component of meeting future electricity needs across the state. Declining development costs combined with ambitious renewable energy targets and financial incentives have stimulated the recent growth of the solar industry. Specifically, the Virginia Clean Economy Act signed into law in 2020 validates the statewide importance of the solar industry by committing Virginia to generate electricity exclusively from carbon-free sources by 2050.

In response to statewide clean energy goals and the decreasing technology costs, large utility-scale solar facilities have quickly become the primary source of new renewable electricity generation in Virginia. Utility-scale solar facilities cover large areas of land with ground-mounted photovoltaic solar panels and operate as power plants feeding electricity into the grid for off-site use. While the exact definition of utility-scale solar often varies, this research defines a utility-scale solar facility as any solar facility owned by a utility or independent power producer with a generating capacity greater than or equal to 5 megawatts (MWac). This plan is only about utility-scale solar facilities and therefore refers to them simply as solar facilities. This does not mean that other scales and types of solar are unimportant, however, they are not the focus of this research.

While solar facilities are a viable source of clean energy with many economic opportunities available to developers, landowners, and local communities, their recent deployment has led to a growing recognition of potential land use conflicts. The declining technology costs, tax breaks, financial incentives, and affordability of rural lands have been the main drivers of the recent development of solar facilities across Virginia. However, as these facilities grow larger and more prevalent, they will become an increasingly important component of local land use patterns in many parts of rural Virginia. Accordingly, proper land use planning serves a critical role in ensuring that Virginia successfully meets future clean energy goals while also promoting sustainable and efficient land use practices.

1.1 | Project Purpose

Analyzing the ongoing land use impacts of utility-scale solar development, establishing a process for tracking future land use patterns, and providing guidance to consider the best land use practices is the primary purpose of this plan. The goal of this plan is not to undermine the opportunity and potential of solar energy. Instead, this plan seeks to inform solar energy development policies through a land use planning perspective to promote the sustainable development of solar facilities.

Balancing the economic opportunity of solar facilities along with an additional emphasis on local land use is a priority in this research. The concept of sustainable development informs this work by accentuating the collective importance of economics, equity, and the environment. Sustainability implies the need to balance the economic potential of solar energy with the need to protect the environment and promote equity. Therefore, this plan demonstrates that land use efficiency is an important component of fully realizing the potential of solar energy in Virginia.

Given the anticipated development of rural land for solar facilities, it is particularly important to quantify existing land use impacts to help develop clear project siting recommendations and policy guidance to direct future development. This plan first analyzes the current land use impacts of solar facilities in Virginia. Additionally, this research also investigates more site-specific characteristics related to the siting of solar facilities. Finally, these findings are considered to develop appropriate goals, objectives, and strategies for guiding future development. Ultimately, this plan supports the work of local land use planners, environmental planners, and energy planners. Solar development occurs in a space where land for agricultural production, housing, commercial development, and environmental conservation all converge. This plan, therefore, considers a variety of interests to promote the sustainable development of utility-scale solar across Virginia.

1.2 | Client Description

Virginia's Department of Mines, Minerals and Energy (DMME) has been tasked with helping to achieve the state's 2050 goal of carbon-free electricity generation. An important component of this transition to renewable energy is solar energy which is overseen by the Virginia Solar Energy Development and Energy Storage Authority within the DMME. As a state agency that actively encourages the implementation of new solar development in Virginia, DMME provides a variety of reports to lawmakers and localities to assist in decision-making processes related to energy. Underlying these actions is an emphasis on encouraging a collaborative approach to meeting the future energy needs of Virginia. This plan merges the solar energy goals of the state with relevant local land-use planning considerations. The detailed analysis of the existing conditions and impacts of utility-scale solar provided in this plan will help DMME to understand the relevant factors of solar energy development more fully. This will allow DMME to promote the best interests of Virginians and their efforts to reach the 2050 clean energy goal.

1.3 | Outline of the Plan

This plan includes an analysis of the land use of solar facilities in Virginia and provides recommendations to encourage the sustainable development of future utility-scale solar facilities. The main components of this plan are:

- Background: A description of the existing conditions and regulatory framework specific to utility-scale solar in Virginia is provided. The general existing knowledge related to the development of solar facilities across the country and world is also discussed. Additionally, the theoretical framework subsection explains how this plan is related to a much broader understanding of sustainable development.
- Methodology: The research questions and methods used for the GIS analysis of the spatial characteristics of existing solar facilities are explained. Relevant studies that helped to inform the methods of this research are also presented. This section also describes the data sources and GIS processes used to analyze the land use of solar facilities.
- Research Findings: The results of the GIS analysis are presented and discussed. This includes assessing various environmental and social characteristics of solar facility sites in Virginia, such as location, area, land cover, conservation quality, farmland suitability, and the demographics of local communities.
- Conclusion: The main findings of this research are summarized and contextualized within the larger discussion of renewable energy, and land use and environmental planning.
- Recommendations: Based on the methods and findings of this research, this section considers topics for future analysis and suggests policy options to guide the sustainable development of new solar facilities in Virginia.

2.0 | Background

Newly updated policies, incentives, and energy portfolio standards in Virginia have helped to stimulate the rapid development of solar facilities in recent years. The development of solar energy facilities in Virginia however has occurred with little understanding of the overall land use impacts. This section provides the necessary context to better understand the motivations of this research. This includes a discussion of current conditions in Virginia, as well as an acknowledgment of the opportunities and challenges of utility-scale solar development. Additionally, this section reviews the overall existing knowledge about utility-scale solar beyond Virginia.

2.1 | Study Area

This research examines all operating utility-scale solar facilities in Virginia to better understand current conditions and provide recommendations for future development. As of January 2021, a total of 38 solar facilities in Virginia (greater than five (5) megawatts in generating capacity) were actively generating electricity with several other projects also under construction and in the permitting phases. The operation of these types of solar facilities in Virginia first began in 2016, and so far, most of the development has been confined to the eastern and southern portions of the state. This research focuses on the acreage, capacity, and location of active solar facilities as of January 2021. This includes facilities in partial operation, but not yet operating at full capacity. The overall size and capacity of facilities in this study are estimated as of January 2021 and may not represent the final size or capacity of a given facility upon the completion of project construction.

Table 1. *Existing Utility-Scale Solar Facilities in Virginia (as of January 2021)*

Name	MW Capacity	County	Service Date
Eastern Shore Solar	80	Accomack	2016-12
Scott Solar	17	Powhatan	2016-12
Woodland Solar	19	Isle of Wight	2016-12
Whitehouse Solar	20	Louisa	2016-12
Clarke Solar	10	Clarke	2017-07
Remington Solar	20	Fauquier	2017-10
Correctional Solar	20	New Kent	2017-11
Sappony Solar	20	Sussex	2017-11
Buckingham Solar	19.8	Buckingham	2017-11
Cherrydale Solar	20	Northampton	2017-11
Oceana Solar	17.6	Virginia Beach City	2017-12
Scott-II Solar	20	Powhatan	2017-12
Essex Solar	20	Essex	2017-12
Southampton Solar	100	Southampton	2017-12
Palmer Solar	5	Fluvanna	2017-12
Martin Solar	5	Goochland	2017-12
Kentuck Solar	6	Pittsylvania	2018-05
UVA Hollyfield Solar	17	King William	2018-09
Puller Solar	15	Middlesex	2018-10
Montross Solar	20	Westmoreland	2018-12
Gloucester Solar	19.9	Gloucester	2019-04
Colonial Trail West Solar	142.4	Surry	2019-12
Rives Road Solar	19.7	Prince George	2020-05
Myrtle Solar	15	Suffolk City	2020-06
Pamplin Solar	15.7	Appomattox	2020-07
Grasshopper Solar	80	Mecklenburg	2020-07
Hickory Solar	20	Chesapeake City	2020-08
Mechanicsville Solar	20	Hanover	2020-09
Spotsylvania Solar	300	Spotsylvania	2020-09
Irish Road/Whitmell Solar	10	Pittsylvania	2020-10
Spring Grove I Solar	97.9	Surry	2020-10
Danville Solar	12	Pittsylvania	2020-11
Greensville County Solar	80	Greensville	2020-12
Twittys Creek Solar	13.8	Charlotte	2020-12
Gardy's Mill Solar	14	Westmoreland	2020-12
Briel Farm Solar	18.8	Henrico	2020-12
Sadler Solar	100	Greensville	2021-01
Bluestone Solar	50	Mecklenburg	2021-01

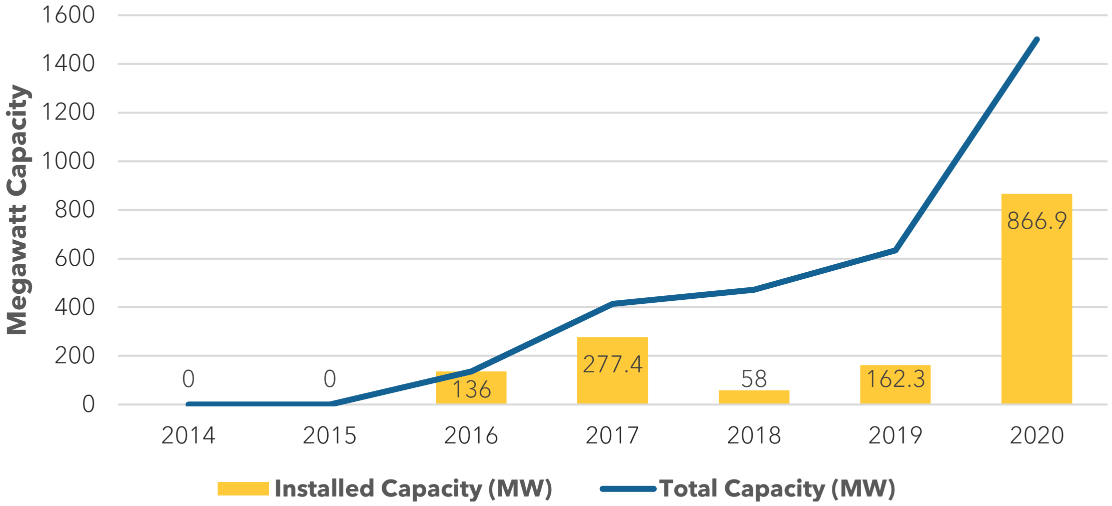
Source: U.S. EIA Monthly Electric Generator Inventory/PJM Interconnection Queue

2.2 | Context of Utility-Scale Solar in Virginia

Trends of Solar Development in Virginia

Across the United States and the world, the cost of solar development has experienced a notable decline over the past decade. Estimates from the International Renewable Energy Agency suggest that the cost of utility-scale solar electricity generation has declined 82% worldwide since 2010.[1] Similarly in the United States, the median installed cost of solar photovoltaic facilities has fallen by 70% since 2010.[2] These cost declines have led to the increasing prevalence of new solar facilities across the country including in Virginia (*Figure 2*). Nationwide, the U.S. was approaching 100,000 megawatts of installed solar generating capacity in early 2020 up from just 10,000 megawatts in 2010. For reference, a single (1) megawatt-hour of electricity can power an estimated average of 200 homes in Virginia.[3]

Figure 2. *Annual Installations of Utility-Scale Solar by Generating Capacity in Virginia*



Source: *U.S. EIA Monthly Electric Generator Inventory/PJM Interconnection Queue*

Despite the rapid decline in the cost of solar technology, current development has not been evenly distributed across the country. While environmental factors help to explain some of the discrepancies, state programs and policies are a major reason for the concentration of existing and planned solar projects in specific states. With a total of 2,310 megawatts of solar energy installed as of December 2020 based on SEIA estimates, Virginia ranked 11th nationally in total solar capacity.[4] Additionally, Virginia and its neighbors in the South Atlantic region have proven to be a hotspot for recent solar facility development due to favorable state policies and financial incentives. The South Atlantic region leads the country in newly installed utility-scale solar capacity in each of the past three years.[5] In neighboring North Carolina, the state ranks 3rd nationally in solar generating capacity trailing only California and Texas in total solar generating capacity due to solar-friendly policies first initiated in 2007. New policies passed in Virginia in 2017 and more recently in 2020 and 2021 allows

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[1] IRENA (International Renewable Energy Agency, “Renewable Power Generation Costs in 2019.”

[2] Mark Bolinger, Seel, and Robson, “Empirical Trends in Project Technology, Cost, Performance, and PPA Pricing in the United States – 2019 Edition.”

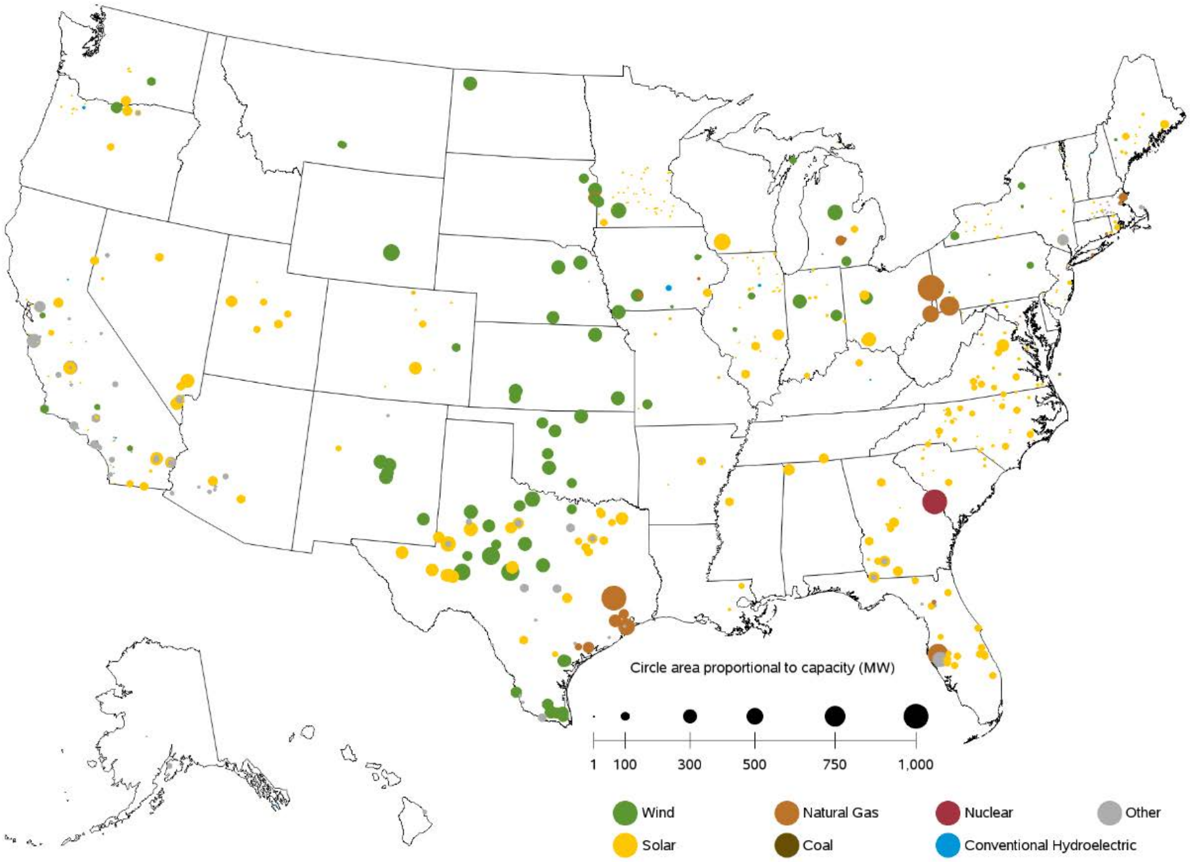
[3] Solar Energy Industries Association, “What's in a Megawatt.”

[4] Solar Energy Industries Association, “Virginia Solar.”

[5] U.S. Energy Information Administration (EIA), “Most New Utility-Scale Solar in the United States Is Being Built in the South Atlantic - Today in Energy - U.S. Energy Information Administration (EIA).”

Virginia to join other solar-friendly states that actively encourage the installation of new solar facilities. As shown in *Figure 3*, all new utility energy generation facilities planned for 2021 in Virginia will come from solar sources. As a result, the Solar Energy Industries Association (SEIA) now ranks Virginia 6th nationally for projected growth in solar capacity over the next 5 years. Virginia also ranked 4th in total generating capacity of new solar installations in 2020 according to SEIA.

Figure 3. *Planned Utility-Scale Generation Projects to Become Operational in 2021*



Source: U.S. EIA Monthly Electric Generator Inventory November 2020

Recent legislation passed in 2020 helps to explain why Virginia is quickly becoming a national leader in new solar development. The 2020 Virginia Clean Economy Act (HB 1526) and HB 714/SB94 are the drivers of this change as it commits Virginia in tandem with the major local utilities (Dominion Power and Appalachian Power) to produce electricity exclusively from carbon-free sources by 2050. This goal will ultimately require a massive shift in the state's electricity generation since 54.4% of net electricity generation in Virginia as of November 2020 came from carbon-intensive fuels such as petroleum, natural gas, and coal.[6] Only 5.6% of net electricity generation in Virginia as of November 2020 came from nonhydroelectric renewable sources such as wind and solar.[7] As a result, the

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[6] "Virginia - State Energy Profile Overview - U.S. Energy Information Administration (EIA)."

[7] Ibid

Virginia economy and the energy sector specifically will likely experience a major transformation in the coming years centered around renewable energy.

In addition to the Virginia Clean Economy Act, the Virginia General Assembly also recently passed many complementary laws to encourage a transition to clean energy which includes facilitating the development of utility-scale solar projects.[8] This new legislation offers a variety of incentives for developers and localities to consider. This includes allowing localities to negotiate siting agreements, establish revenue sharing programs, consider an exemption from the Machinery and Tools tax, and require cash payments or public improvements from solar developers. Collectively, this new legislation presents several opportunities for localities to work with solar developers to approve more solar facilities across the state.

Current Regulatory Process

Beyond the economic opportunity and clean energy potential of solar energy, the impact of solar development on the physical environment and local communities remains a relevant focus of the regulatory process. The current review and permitting process of solar facilities in Virginia is divided among various entities at the state and local levels. While this process has streamlined project approval, this regulatory system has not widely considered or compiled estimates of the overall statewide land use impacts of utility-scale solar.

Currently, the permitting of solar facilities in Virginia at the state level largely promotes the expedited development of new facilities. Smaller solar sites between 500 KW and five (5) MW in capacity or with a footprint between two (2) and ten (10) acres only need to provide notification to the Virginia Department of Environmental Quality (DEQ) and are not subject to a full review. Solar facilities greater than ten (10) acres in size and between five (5) MW and 150 MW in generating capacity are however subject to a review process through the application for a Permit by Rule (PBR) from the DEQ. Most existing projects in Virginia are in this size range and have been permitted through the PBR process from the DEQ. The components of the PBR application include an air quality analysis, assessments of cultural, wildlife, and natural heritage resources, a site and context map, a public comment period, and certification of local government approval. Larger projects over 150 MW in capacity are not subject to DEQ review and instead go through a more rigorous review process with the State Corporation Commission (SCC). Ultimately these separate state review processes have helped to expedite the permitting of new solar facilities but have also made it difficult to fully understand the extent of development and quantify the total statewide land use impacts of utility-scale solar facilities.

All solar facilities are also permitted by local governments to ensure that a project complies with all local land use ordinances. As a result, compliance with local land use requirements is an important aspect of regulating the development of solar facilities. Since solar facilities can require a large land area, localities often must consider balancing the interests of future growth areas, prime farmland, sensitive environmental or historic sites, and adjacent business or residential interests. Potential impacts include ecological changes, loss of scenery, restrictions in future development potential, a decline in agricultural production, and change in the character of an area. Given the variety of local land use factors that are considered when approving solar facilities, local and regional planners have

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[8] See Virginia LIS website to review overviews of each bill passed in the 2020 and 2021 sessions

an important role in providing clear guidance on how the development of solar projects can be mutually beneficial for a local community and the state of Virginia's overall energy needs.

Potential Impacts of Utility-Scale Solar in Virginia

Virginia may ultimately need to dedicate hundreds of thousands of acres of land to renewable energy production to meet future electricity needs from carbon-free sources. The broader implications of this potential large use land however are not well understood or contextualized. The potential loss of forested or agricultural land remains an obvious concern of the unconstrained growth of the solar industry. Despite the extensive amount of agriculture and forested land in the state, the prevalence of both land uses has already been declining because of development pressures from new sprawling residential and commercial uses. The emergence of solar facilities, if not properly managed, represents another significant threat to these important natural resources in Virginia. While the present review and approval process does consider some of these land use factors, a broader understanding of the collective impacts across the state is necessary.

As of 2021, most existing projects have been built with a capacity close to 20 megawatts and covering between 100 and 200 acres of land. However, much larger solar facilities are becoming more common across Virginia. The most notable and well-publicized utility-scale project to be proposed and approved in Virginia is the s-Power Pleinmont Solar Facility (Spotsylvania Solar Energy Center) in Spotsylvania County which is currently under construction and partially in operation. At an expected capacity of 500 MW, 1.8 million panels, and an area of 6,350 acres, the project is the fifth largest in the United States and the largest solar project east of the Rockies. Due to its extreme size, the project met opposition from several local stakeholders that contended that the very large industrial complex was inappropriate for the historic and rural character of the county.[9] Specifically, many local residents feared that a project of such size would disturb the ecosystem, lead to lower property values, and cause irreparable damage to the local forest.[10]

Given the expected increase in the number and size of solar facilities across Virginia, many localities will likely face similar difficult land use decisions. While 38 utility-scale solar projects are currently in operation, the DEQ has issued dozens of permits (PBRs) for new solar facilities in the coming years and has also received many notices of intent for potential projects. This suggests that Virginia will continue to see the growth of the development of new solar facilities in the next decade. This demonstrates the importance of beginning to understand the current land use impacts of utility-scale solar facilities and develop improved siting practices.

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[9] Jacob Fenston, "A Battle Is Raging Over The Largest Solar Farm East Of The Rockies.'"

[10] Pappas, "Massive East Coast Solar Project Generates Fury from Neighbors."

2.3 | Existing Knowledge

The transition to a carbon-free energy sector in Virginia is a part of a much larger worldwide acknowledgment of anthropogenic climate change caused largely by greenhouse gas emissions which has led to an increased reliance on renewable energy sources such as solar.[11] Since the sun is the most abundant energy source of renewable energy in the world, solar energy facilities of various types have steadily developed all over the world because of the relative availability, cost-effectiveness, accessibility, and efficiency of solar energy compared to other renewable energy sources.[12] Solar energy, therefore, offers significant economic, ecological, and equity benefits if properly implemented.

The Emergence of the Solar Industry

Given the potential of solar energy to help satisfy future energy demand, photovoltaic (PV) solar energy, which is the energy obtained directly from solar radiation conversion, has quickly become both an important energy source and a unique investment opportunity. The capturing of solar energy with PV panels to produce electricity is one of the most promising markets of the renewable energy sector because of recent technological advancement, high levels of investment, and a fast growth perspective.[13] As a result, solar PV electricity is expected to be the largest, least costly, and most prominent source of energy in the long term in the next 50 years.[14] With the proper technological advancements and policy support, estimates suggest that PV solar could supply 30-50% of electricity in competitive markets by 2050.[15]

The recent improvements in solar PV technology have allowed small distributed solar generating units to prosper in a variety of residential, commercial, and industrial settings. However, utility-scale PV solar facilities remain the primary type of solar energy generation in the United States accounting for 66% of the total net generation of electricity from solar sources in 2020.[16] Despite inefficiencies in land use and transmission compared to distributed solar systems, utility-scale solar facilities have deployed new solar technologies at a much faster rate and at lower costs due to the increased ability to attract financial capital and achieve economies of scale in the construction and operation phases of the projects.[17] As a result, utility-scale solar facilities remain an important part of a clean energy future because of their ability to reduce the delivered cost of power compared to other renewable energy sources.

Potential Impacts of Solar Development

The land impacts of solar energy development can be complex and are often dependent on the location, site design, and type of technology used. While solar energy is widely considered a more efficient and clean energy source, the widespread implementation of utility-scale solar facilities may impact large areas of land and place development pressure on many undeveloped rural areas.[18] Land impacts however are not unique to the development of solar energy facilities. Regardless of the energy source used, electricity generation is inherently a land-intensive process. Energy sprawl

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[11] Karl and Trenberth, "Modern Global Climate Change."
[12] Kannan and Vakeesan, "Solar Energy for Future World."
[13] Sampaio and González, "Photovoltaic Solar Energy."
[14] Breyer et al., "On the Role of Solar Photovoltaics in Global Energy Transition Scenarios."
[15] Creutzig et al., "The Underestimated Potential of Solar Energy to Mitigate Climate Change."
[16] "Electric Power Monthly - U.S. Energy Information Administration (EIA)."
[17] Mendelsohn, Lowder, and Canavan, "Utility-Scale Concentrating Solar Power and Photovoltaic Projects."
[18] Poggi, Firmino, and Amado, "Planning Renewable Energy in Rural Areas."

resulting from the energy development necessary to meet growing energy demands is already the largest driver of land use change in the United States. Estimates suggest that energy development could lead to a direct land use change of up to 2,500 square miles of land per year in the United States through 2040.[19] Based on recent estimates, the total land use requirements for small and large PV installations nationwide have a capacity-weighted average of 8.9 acres per MW of production.[20] This means that large-scale projects over 100 MW in size can easily cover thousands of acres of land. Based on similar capacity averages, utility-scale PV could eventually use up to 17,000,000 acres of land nationally.[21] In Virginia specifically, the total per capita solar footprint required to achieve state energy needs is estimated at 233 square meters per person which could occupy around 1.6% of the state's total land area.[22]

While solar may require an extensive amount of land, studies have viewed the land use requirements of solar favorably as compared to other energy sources. Using either a land use intensity or power density metric for assessing land use requirements, solar has been found to initially require a much larger direct land footprint for the same amount of power generation.[23] However, solar and other renewables can use the same plot of land indefinitely unlike extractive energy sources that must expand their footprint to acquire additional resources. Consequently, over the full-time horizon of the life cycle of an energy production project, solar may ultimately require a smaller land footprint for an equivalent of cumulative energy production.[24] Additionally, proximity to PV solar facilities is considered much safer than other energy sources, meaning they also require less additional land for buffering and spacing from other uses. Finally, solar facilities are considered less time-intensive and therefore are less likely to cause long-lasting harm to the quality of land at a particular site.[25]

Although the impacts of solar may be preferable to fossil-fuel generated energy, its development still requires a careful evaluation of trade-offs between land, energy, and ecology.[26] Depending on the location and size of a solar facility, specific impacts may include land conversion, agricultural productivity impacts, ecosystem modifications, habitat reduction, aesthetic changes, and adjustments to recreational potential.[27] Since solar facilities initiate a sudden change in land use, they can cause a variety of environmental and ecological changes both during construction, and once the facility is operational. Many of the construction impacts are the result of increased traffic and land disturbance activities, but strategies have emerged to mitigate many of these short-term impacts. By comparison, the long-term environmental impacts of solar projects are not as well understood. Changes in albedo, land temperature, microclimates, erosion, dust production, soil contamination, water pollution, precipitation regimes, and noise pollution have all been considered possible impacts of large solar projects.[28] Land cover change resulting from solar development could also lead to alterations of nutrient dynamics, exotic plant invasions, biodiversity loss, habitat loss and fragmentation, water stress, and species loss.[29] While some of these impacts have been

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[19] Trainor et al., "Energy Sprawl Is the Largest Driver of Land Use Change in United States."

[20] Ong et al., "Land-Use Requirements for Solar Power Plants in the United States."

[21] Shum, "A Comparison of Land-Use Requirements in Solar-Based Decarbonization Scenarios."

[22] Denholm and Margolis, "Land-Use Requirements and the per-Capita Solar Footprint for Photovoltaic Generation in the United States."

[23] Wachs and Engel, "Land use for United States power generation: A critical review of existing metrics"

[24] Fthenakis and Kim "Land use and electricity generation: A life cycle analysis", Trainor et al., "Energy Sprawl Is the Largest Driver of Land Use Change in United States."

[25] Turney and Ftheankis, "Environmental Impacts from the Installation and Operation of Large-scale Power Plants".

[26] Moore-O'Leary et al. "Sustainability of utility-scale solar energy- critical ecological concepts"

[27] Boer et al., "Local power and land use: spatial implications for local energy development."

[28] Hernandez et al., "Environmental Impacts of Utility-Scale Solar Energy."

[29] Ibid

more closely examined, very few solar facilities have existed for long enough to fully evaluate many of the possible negative impacts.

Solar facilities also have impacts on local communities that can influence the public perception of future solar development projects. While the general opinion of renewable energy is largely positive, the development of large solar facilities projects without adequate public input in local areas can create backlash most closely linked to proximity, a concentration of uses, and visual intrusion.[30] Place attachment, socio-demographic characteristics, and project-related characteristics such as size, proximity, and visibility have also proven to be relevant factors that explain local support or opposition to solar development projects.[31] Many local communities have also expressed concern about the future decommissioning process. Traditional land use regulations do not adequately consider the concept of reversibility, which has led to uncertainty about the long-term impacts of solar development in local communities.[32] These local impacts and uncertainties have ultimately made solar energy development a contentious issue in some rural communities.

Interventions and the Role of Planners

In response to the potential land use conflicts initiated by solar facilities, local policymakers and planners have an important role in coordinating local land use regulations and policies to either promote or limit the development of solar facilities. The connection between land and solar energy generation creates an important role for local land use and environmental planning within the context of energy development. [33] This means that local and regional planners will ultimately have an important influence on the future of renewable energy.

By better understanding the potential impacts of solar development, planners can promote improved land use practices and sustainable development through siting agreements, local regulations, and policy innovations. The emergence of GIS methodology to assess renewable energy impacts and identify ideal sites for development is a promising method for improving future solar development.[34] Through the use of GIS and statistical tools, planners can compare scenarios of solar development with competing land uses to best protect agricultural and conservation interests while still encouraging new solar development.[35] Further GIS assessments have also begun to include social preference data into site suitability analyses.[36] By using this information, planners can make more informed updates to zoning ordinances and comprehensive plans to better guide the future siting of solar facilities.

Planners have also begun to consider a variety of options to best accommodate large-scale solar projects. The use of brownfields, previously disturbed lands, and abandoned mined lands for solar projects represents an opportunity for development without the need for additional land disturbance.[37] The potential of agrivoltaic systems that can support both the colocation of PV systems and agriculture on the same plot of land has been explored as another siting

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[30] Kontogianni et al., "Planning Globally, Protesting Locally."
[31] Carlisle et al., "Utility-Scale Solar and Public Attitudes toward Siting."
[32] Boer et al., "Local power and land use: spatial implications for local energy development."
[33] Kaza, Nikhil & Curtis Marie Patane "The Land Use Energy Connection"
[34] Poggi, Firmino, and Amado, "Planning Renewable Energy in Rural Areas."
[35] Dias et al., "Interplay between the Potential of Photovoltaic Systems and Agricultural Land Use."
[36] Brewer et al., "Using GIS Analytics and Social Preference Data to Evaluate Utility-Scale Solar Power Site Suitability."
[37] Klusáček et al., "From Wasted Land to Megawatts."

consideration.[38] Planners can also play an important role in gathering and incorporating localized land use information that may not be readily available to developers to facilitate and encourage proper siting practices. This includes information on rights-of-way, previously disturbed lands, productive agricultural land, growth boundaries, and local conservation priorities.

2.4 | Theoretical Framework

The primary purpose of this plan is to promote the sustainable development of solar facilities. Although solar facilities are a form of renewable energy that can reduce the negative environmental impacts of fossil fuels, the long-term sustainability of solar facilities must consider all the relevant environmental, economic, and social perspectives. Specifically, solar facilities can have significant impacts at the local level. Accordingly, many of the outcomes and recommendations for this plan focus on promoting solar energy as a form of sustainable energy development when proper land use practices are considered.

The concept of sustainable development has progressed from a vague idea to a more relevant aspect of the modern practice of land use planning that is particularly useful for framing this research. Broadly, the definition of sustainability as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" from the 1987 Brundtland Commission remains the most recognizable definition.[39] For planners, the concept of sustainable development includes finding a balance between the interests of equity, environment, and economic efficiency to minimize conflicts that arise over development, property, and natural resources.[40] Within the context of the development of solar facilities, a sustainable outcome requires maintaining a similar balance between competing interests. These competing interests include the environmental implications of land use conversion, the economic potential of solar development as a fossil fuel replacement, and the unequal distribution of opportunity and burden that specific rural communities face as a part of the siting of new solar facilities.

This means that if solar facilities are considered to be an effective replacement to conventional energy sources, the sustainability of solar facilities needs to be assessed. As a result, analyzing the impacts of solar development and properly planning for future solar facilities is important in helping to reach the objectives of sustainable development.[41] Ultimately the potential of solar as a sustainable form of energy orients the focus of this plan towards a balanced solution between competing interests. Specifically, this research expands the analysis of utility-scale solar beyond economic interests to also consider other elements of sustainability such as land use and equity. This research specifically reviews the land use impacts and demographic factors of utility-scale solar development in Virginia to better inform productive land use negotiations in support of the long-range goal of the sustainable development of solar facilities in Virginia.

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[38] Dupraz et al., "Combining Solar Photovoltaic Panels and Food Crops for Optimising Land Use"; Dinesh and Pearce, "The Potential of Agrivoltaic Systems."

[39] WCED (World Commission on Environment and Development), "Our Common Future."

[40] Campbell, "Green Cities, Growing Cities, Just Cities?"

[41] Grilli et a., "A multi-criteria framework to assess the sustainability of renewable energy development in the Alps".

3.0 | Methodology

The process of investigating the land use impacts of utility-scale solar development in Virginia and providing recommendations for improved land use practices includes answering multiple research questions. The primary purpose of this research is to quantify land use change and the local impacts associated with the ongoing development of solar facilities in Virginia. For this research, solar facilities are defined as five (5) megawatts and above in generating capacity since that is the size that triggers a state-level review by the DEQ. Additionally, this research focuses on ground-mounted solar facilities owned either by electric utilities or independent power producers. This analysis does not include any roof-mounted distributed solar systems.

The use of geographic information systems (GIS) software to create a geospatial dataset of the boundaries of active solar facilities was necessary for the analysis of land use in this research. This dataset builds on publicly available information and expands the ability to study local land use impacts and demographic factors more accurately. This research also relies on existing datasets on land cover and demographics to analyze the existing conditions and trends across Virginia. Accordingly, this research strives to:

1) Quantify total statewide land use impacts
2) Review site-specific impacts
3) Consider options for future development

The following research questions guide this process:

- *What is the amount of impacted land area by utility-scale solar facilities in Virginia?*
- *What are the characteristics of the lands occupied by solar facilities in Virginia?*
- *What are the best practices for tracking and regulating the siting of utility-scale solar facilities in order to address long-term sustainability interests?*

3.1 | Sources of Information

The main purpose of this research is to produce and analyze geospatial datasets that detail the location, size, and land coverage of solar facilities in Virginia. While some existing information exists about individual solar facilities, this plan relies heavily on original research. As a result, this research draws on techniques and research methods used elsewhere in the United States.

Although limited, a few published studies have attempted to quantify the land requirements of solar facilities or assess the effect of solar facilities on land use. The National Renewable Energy Laboratory (NREL) in 2013 assessed the land requirements of a sample of solar facilities across the U.S. based on two land use metrics which included the total impacted site area and the direct impact area comprised of land directly occupied by solar arrays.[42] Data on the area of solar facilities was collected from project information from federal, state, or local regulatory agencies. When necessary, the study also referenced data provided by developers and analyzed satellite images to identify the configuration, boundaries, and area solar facilities. This analysis follows a similar data collection process.

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[42] Ong et al., "Land-Use Requirements for Solar Power Plants in the United States."

In California, two complementary studies investigated the spatial distribution, total land use, and land cover change of solar facilities over 20 megawatts in size across the state.[43] These studies involved creating a geospatial dataset of utility-scale solar installations based on the total acreage or footprint of solar facilities as published in official government documentation. These studies only considered the point location of solar facilities and simply allocated size based on the published acreage of individual solar facilities. Land cover change was then estimated by comparing point locations with land cover types from the National Land Cover Dataset (NLCD) at a 30-meter resolution. More recently, a similar study of the land use trends of solar energy development trends was conducted in the state of New York.[44] The study used a one (1) megawatt threshold and also relied on NLCD data to identify land cover change based on the published land footprint sizes and the point location of solar facilities.

Similar land use studies have also been conducted by various public agencies and non-profits. Close to Virginia, work completed by the NC Sustainable Energy Association (NCSEA) and the NC Department of Agriculture & Consumer Services (NCDA&CS) provides a useful framework to contextualize the results of this research. The *Land Use Analysis of NC Solar Installations* report serves as a useful local study that quantified the amount of land conversion from PV systems in North Carolina.[45] Additionally, the *North Carolina Solar and Agriculture Report* by the NCSEA in 2017 provides a practical description of relevant land use changes related to rural agriculture areas which are highly relevant to this research.[46] Finally, in Maryland, the Governor's Task Force on Renewable Energy Development and Siting Final Report provides an example of a quantitative analysis used to forecast future land use impacts of solar development as a basis for recommending improved land use practices.[47]

3.2 | Methods

GIS Analysis of Statewide Land Use Impacts

What is the amount of impacted land area by utility-scale solar facilities in Virginia?

The goal of this research question is to quantify the overall land use impact of utility-scale solar development across Virginia. Specifically, this research first consisted of gathering a total estimate of the current number of acres dedicated to solar facilities in the state. This total acreage estimate is based on the amount of land impacted by each solar facility. This is different from the total acreage of impacted parcels as reported in public permitting documentation. Finding total acreage amounts for each facility included estimating the total disturbed area of each solar facility and the footprint of physical solar panels. This information was collected and compiled in a new geospatial dataset of polygons representing the boundaries of all active facilities in Virginia. Unlike previous studies in other states that relied on point data for the location of solar facilities, this research considers the physical developed boundaries of individual solar facilities using polygon layers drawn with GIS software. All geospatial data was compiled, processed, and analyzed using ArcGIS (10.x) software. Some further statistical analysis was conducted using SPSS 26 software.

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[43] Hernandez et al. "Land-Use Efficiency of Big Solar", Hernandez et al. "Solar Energy Development Impacts on Land Cover Change and Protected Areas".

[44] Katkar et al. "Strategic land use analysis for solar energy development in New York State"

[45] NCSEA, "Land Use Analysis of NC Solar Installations."

[46] Aldina et al., "North Carolina Solar and Agriculture."

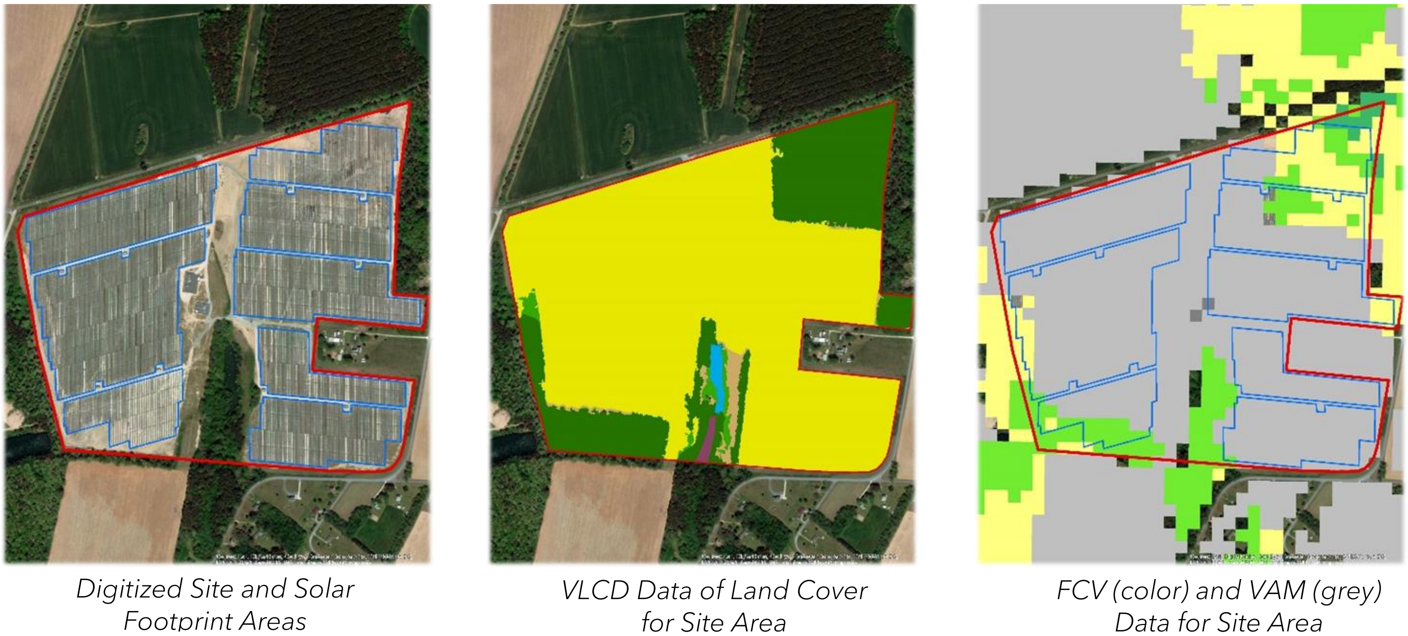
[47] State of Maryland, "Governor's Task Force on Renewable Energy Development and Siting Final Report."

This analysis considers all utility-scale solar facilities over five megawatts (5 MW) in generating capacity in operation as of *January 2021*. This includes solar facilities that were only in partial operation at the time of this research. Subsequently, only the footprint and capacity in operation as of January 2021 were considered. As a result, this data will need to be constantly updated as more information becomes available. In total, this research considers 38 solar facilities with sizes varying from five (5) MW up to 300 MW, with the first solar facilities becoming operational in late 2016.

The U.S. Energy Information Administration's (EIA) data on the size, location, and capacity of all electricity generation sites in the state of Virginia helped to locate most of the existing solar facilities considered in this analysis. Additionally, information from the PJM interconnection queue was referenced to verify and update any missing information from the EIA data. Similar to the 2013 NREL study, the boundaries of existing solar facilities created in this analysis were determined using published site plans in public regulatory documentation, aerial imagery, and the most recent Landsat 8 satellite imagery. This spatial information was then georeferenced and individually digitized into a polygon layer in GIS as accurately as possible. A boundary of the footprint of solar panels at each facility was constructed based on the general contiguous area covered by solar panels. This area does not include the space between rows of panels. A larger total disturbed site area was also created in GIS based on the full site area that extends beyond the physical location of solar panels (See *Figure 4* below). This includes all areas with a visible permanent disturbance or fencing surrounding the facility. This is based on site plan maps when available as well as by visually comparing land cover change based on recent aerial and satellite imagery.

Once a complete geospatial dataset of active solar facilities was created, land cover classifications were isolated at each solar facility. The analysis relies primarily on the 1-meter resolution Virginia Land Cover Dataset (VLCD) that was published in early 2016. This land cover data was collected and published before the operation of any solar facilities in Virginia. Additionally, the less detailed 2016 and 2006 National Land Cover Datasets (NLCD) (30-meter resolution) were included for supplemental findings based on methods used in previous studies. However, the VLCD ultimately

Figure 4. *Visualization of GIS Analysis Methods*



Digitized Site and Solar Footprint Areas

VLCD Data of Land Cover for Site Area

FCV (color) and VAM (grey) Data for Site Area provided a more robust dataset for this research because of its high resolution and availability in vector format for further data processing. The VLCD data includes eleven land cover classifications, with the Forested and Cropland classifications being the two main land covers identified in this analysis. A full description of each VLCD land cover classification is available in Appendix A. The VLCD data in vector format was clipped to each solar facility using the Intersect and Dissolve features in ArcGIS. Given the overall size and spatial extent of VLCD data split into hundreds of individual tiles, the ModelBuilder in ArcGIS helped to streamline the data processing. The workflow for these data processing methods is also provided in Appendix A. Finally, the land cover data was compiled and aggregated into a statewide total based on land cover types.

Site-Specific Analysis

What are the characteristics of the lands occupied by solar facilities in Virginia?

Based on the findings of the first research question, a more detailed analysis of specific relevant variables was conducted to better understand some of the more specific impacts of solar development in Virginia. This includes detailed data on demographics, soil suitability, agricultural production, forest conservation, distance to transmission lines, and proximity to urbanized areas. Since forests and farmlands are the most likely areas to be impacted by the development of solar facilities, it is important to understand the overall quality of those lands that have been dedicated to solar facilities. The Virginia Department of Forestry's Forest Conservation Model (FCV) and the Virginia Department of Conservation and Recreation's Agricultural Model (VAM) were used to quantify the quality of forest and farmlands (See above in *Figure 4*). A full description of the methodology of these datasets can be found in Appendix A. Each of these datasets is at a 30-meter resolution, therefore there are some inconsistencies with the VLCD dataset which is more precise. Nevertheless, the FCV and VAM models offer a useful introduction that helps to describe land use patterns of solar development in more detail. Furthermore, the impacted croplands were further evaluated based on soil quality values from the Virginia Agricultural Model and the types of previously cultivated crops from the United States Department of Agriculture's (USDA) Cropland Data Layer (CDL). This analysis only used CDL data from 2015 which is a single point of time and does not provide a complete depiction of active agriculture patterns. This should be further investigated in the future.

Other locational factors included in this analysis include distance to transmission lines, proximity to urbanized areas, and demographic patterns. The demographic analysis is based on the most recent ACS 2019 5-year estimates for each census tract that contains a solar facility. Specific demographic factors that were analyzed included the median household income, poverty rate, median house value, population density, and proportion of the population by race.

Options to Guide Future Development

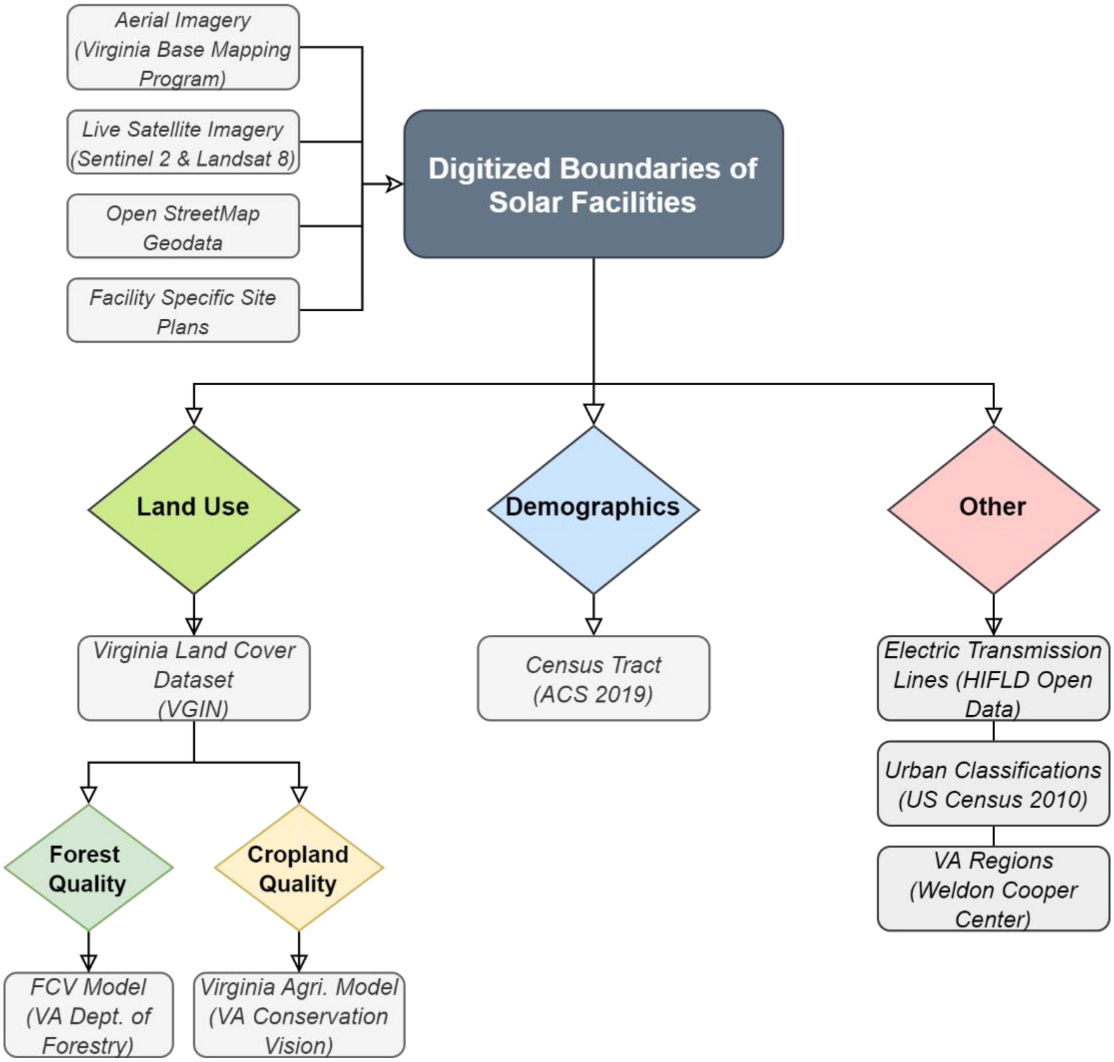
What are the best practices for tracking and regulating the siting of utility-scale solar facilities in order to address long-term sustainability interests?

Finally, to help create pertinent recommendations for the DMME on future administrative roles and policy needs regarding the proper implementation of solar in Virginia, a brief review of best practices from other states in Virginia was conducted. This component of the research is associated with the recommendations section of the plan. The primary focus of this research is to explore if and how other states are collecting, maintaining, and analyzing geospatial information on the development of solar facilities. These best practices largely come from other states that also have experienced rapid development of utility-scale solar. Overall, this best practice research is brief and should be explored in more detail as more adaptive and experimental policy options are explored nationwide.

3.3 | Data Sources

Below is a flowchart depicting the data sources used for the GIS analysis component of this research. The grey boxes represent the various data sources used at each step in the research process. A complete diagram of the GIS workflow and the ArcGIS ModelBuilder used for this research are located in Appendix A as well as details about each data model included in the analysis. This information is useful for being able to replicate and expand this research as more information becomes available and solar facilities continue to be developed across Virginia.

Figure 5. *Data Sources Included in GIS Analysis of Solar Facilities*



4.0 | Research Findings

The following section presents the research findings from each component of the GIS analysis of solar facility sites in Virginia. This includes information about the size and location of solar facilities as well as details about the site of each solar facility such as land cover change, characteristics of impacted forested land and cropland, and the demographics of the surrounding area near solar facilities. Finally, the findings section concludes with a brief discussion of best practices from other states to direct recommendations for future analysis and improved solar facility development.

4.1 | Location

Solar facilities in Virginia are more often located in rural and lightly populated areas in the eastern and southern portions of the state. The general location of Virginia's solar facilities helps to inform many of the subsequent findings of this research regarding land use and demographics. The data presented below provides a general understanding of the overall location of solar facilities in Virginia. However, the information in this section should be frequently updated as more solar facilities are constructed in Virginia to better understand ongoing and emerging land use trends.

First, as demonstrated in *Figure 6* and *Table 2*, solar facilities are primarily located in the eastern and central portions of the state. The regions used in this analysis are defined by the UVA Cooper Center as demographic regions with shared economic and cultural ties. Southside, Central, Hampton Roads, and Eastern Virginia have experienced most of the recent solar facility development. Within these regions, rural localities with small populations (*Table 3*) are more likely to have a solar facility.

Figure 6. *Size and Location of Utility-Scale Solar Facilities in Virginia (January 2021)*

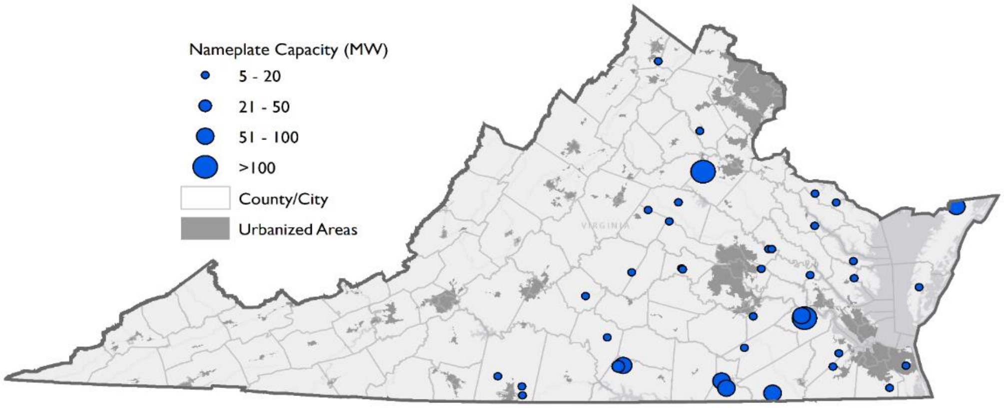


Table 2. *Solar Facilities in Virginia Regions*

Region	Total Facilities
Central	10
West Central	1
Southside	11
Hampton Roads	7
Eastern	6
Southwest	0
Northern	3
Valley	0

Table 3. *Solar Facilities by Population Size of Locality*

Locality Population Size	Total Facilities
Greater than 100,000	5
75,000 to 100,000	1
50,000 to 75,000	4
30,000 to 50,000	7
15,000 to 30,000	11
Less than 15,000	10

Additionally, Metropolitan Statistical Areas and Urbanized Areas provide further detail about the location of solar facilities and their proximity to urban and rural areas. Metropolitan Statistical Areas (MSAs) is a geographic region with a relatively high population density with shared economic ties. A total of 23 out of 38 solar facilities are in either a Metropolitan or Micropolitan Statistical Area. Since MSAs follow county boundaries, this classification does not accurately differentiate the difference between urban and rural areas. The Census Bureau's Urbanized Area classification provides a more accurate depiction of urban and rural areas. These are the core of an MSA with a high population density. Urbanized Areas have a population of over 50,000 while Urbanized Clusters have a population of less than 50,000. Based on this classification, 25 solar facilities are greater than three (3) miles from either an urbanized area or urbanized cluster and therefore are considered to be located in rural areas.

Table 4. *Solar Facilities in Metropolitan Statistical Areas*

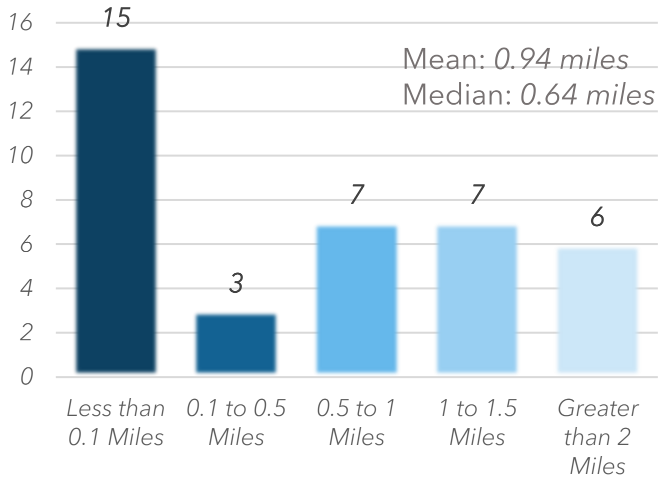
Census Statistical Area	Total Facilities
Metropolitan Statistical Area	**20**
Richmond MSA	9
VB-Norfolk-Newport News MSA	5
Washington-Arlington-Alexandria MSA	3
Charlottesville MSA	2
Lynchburg MSA	1
Micropolitan Statistical Area	**3**
Danville MSA	3
Outside an MSA	**15**

Table 5. *Solar Facilities Near Urbanized Areas*

Proximity to Urbanized Areas	Total Facilities
Urbanized Area: UA (Pop. >50,000)	
Inside UA	2
Less than 1 mile from UA	4
Less than 3 miles from UA	6
Urbanized Cluster: UC (Pop. <50,000)	
Inside UC	0
Less than 1 mile from UC	6
Less than 3 miles from UC	7
Rural	
Greater than 3 miles from UA/UC	25

Finally, another important locational consideration is the distance of solar facilities to electricity transmission lines. To date, most solar facilities have been built in very close proximity to existing transmission lines due to the lower costs in supplying electricity into the grid. A total of 25 of the state's 38 solar facilities are located less than one mile from a distribution line. Only one solar facility is located greater than five miles from a distribution line.

Figure 7. *Distance of Solar Facilities to Nearest Transmission Line*



4.2 | Size and Area

Based on the location and boundaries of the 38 operational solar facilities in Virginia, a total of 13,842 acres of land has been disturbed by solar facilities. The solar facilities in this analysis represent approximately 1,500 MW of total generating capacity as of January 2021. The average acres of disturbed land per megawatt of generating capacity for all solar facilities in Virginia is 7.9 acres per megawatt (MW). However, facilities in Virginia have ranged from as low as 4.9 acres per MW up to 14.3 acres per MW (*Figure 9*). The topography, previous land cover, accessibility, parcel shape, and surrounding features seem to influence the ratio of disturbed acres to megawatt capacity of different solar facilities.

Similarly, the total area of the footprint of contiguous solar panels of solar facilities in Virginia equals about 6,793 acres. This is a rough estimate of the total footprint area and does not include the space between rows of panels. Based on these estimates, the solar panel footprint accounts for roughly half (50%) of the total disturbed area of utility-scale solar facilities in Virginia. Like the total disturbed site area, the panel footprint area per MW varies by facility (*Figure 10*).

Total Disturbed Area of Utility-Scale Solar Sites:
13,842 acres

Average Acres per MW (Total Disturbed Area):
7.9 acres/MW

Total Area of Solar Panel Footprint:
6,793 acres

Average Acres per MW (Solar Panel Footprint Area):
4.5 acres/MW

The estimates of the disturbed site area in this analysis are often much smaller than the total acreage listed in permitting documentation from the Department of Environmental Quality, the State Corporation Commission, or specific localities. The total published acreage for a solar facility in permitting applications typically includes the area of all parcels included in the project regardless of the physically developed area. The total disturbed area of solar facilities calculated in this analysis equals about 73% of the total permitted area of the facilities (18,930 acres). On average, the disturbed area of an individual solar facility covers about 68% of the total area published in permitting documentation. *Figure 8* provides a visual example of the difference between the actual disturbed area and the total permitted area of a specific solar facility site.

Figure 8. *Comparison of Site Areas of Greensville County Solar Facility*

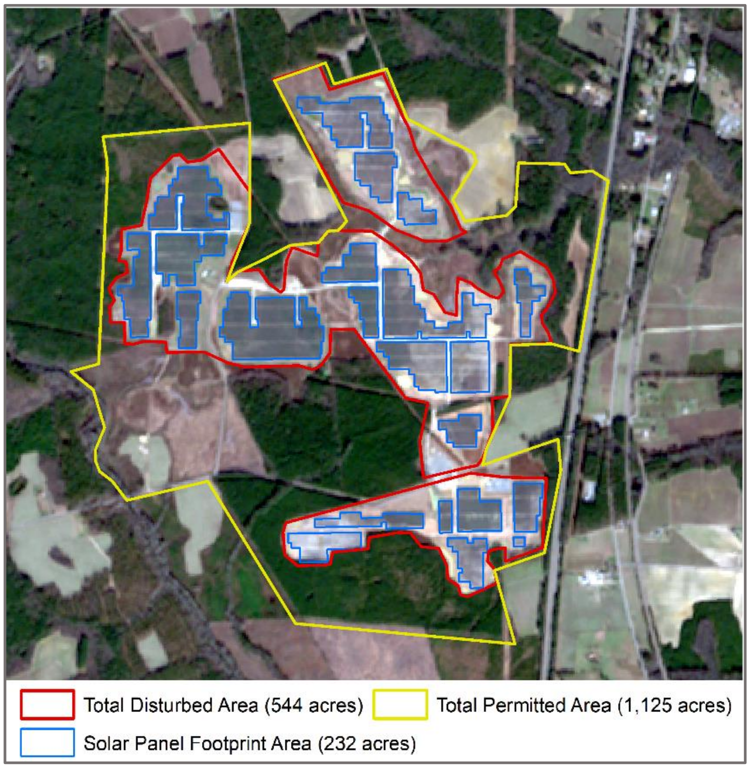


Figure 9. *Distribution of the Disturbed Site Area per Megawatt Ratio of Solar Facilities*

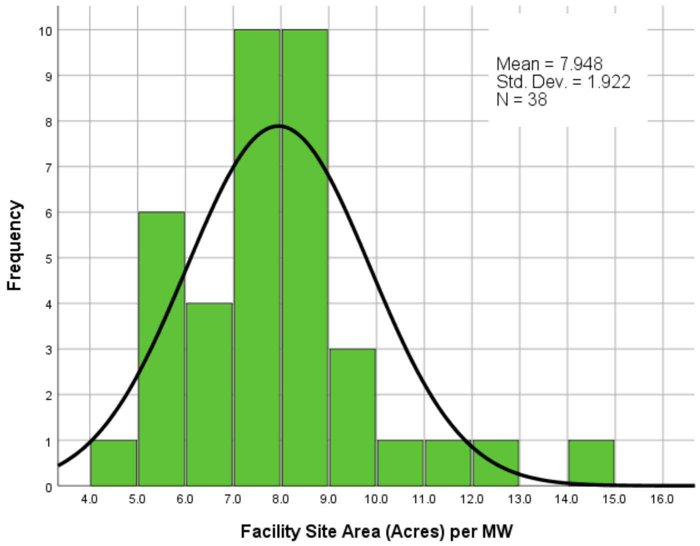
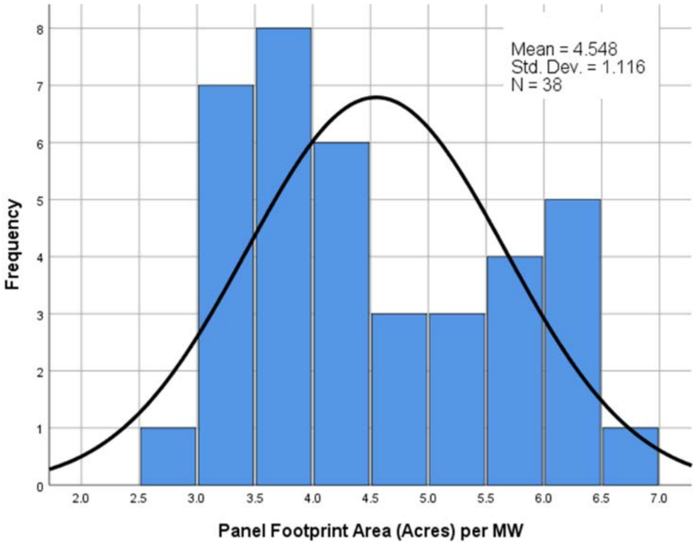
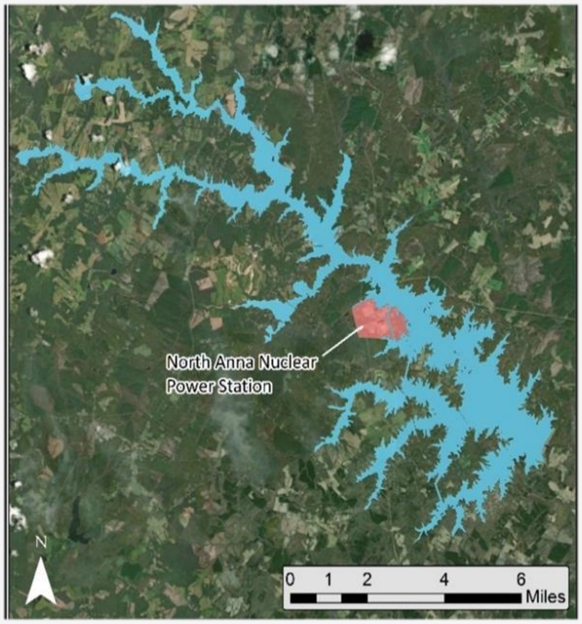


Figure 10. *Distribution of the Solar Panel Footprint Area per Megawatt Ratio of Solar Facilities*



Size Comparisons

Figure 11. *Size of Lake Anna as an Area Comparison*



For context, the 13,842 acres of land disturbed by solar facilities amounts to about 0.05% of all Virginia land area. This is roughly the same size as Virginia's Lake Anna (~13,000 acres). Lake Anna was originally constructed in 1972 after Dominion Energy purchased close to 18,000 acres of farm and timber lands to provide cooling water for the North Anna Nuclear Power Station. Like solar facilities, the reservoir required the conversion of forest and agricultural land into a reservoir to help serve energy generation needs. The North Anna Nuclear Power Station itself sits on a 1,075-acre site and has a capacity of 1,892 MW.

In 2020, the North Anna Power Station generated 15.8 million megawatt-hours (MWh) of electricity. With an annual capacity factor averaging over 90%, the North Anna Power Station can produce more electricity than a similar area dedicated to solar energy generation.[48] For example, the 1,500 MW of installed utility-scale solar capacity in Virginia could produce an estimated 3.2 million MWh annually based on an average capacity factor for solar of 24%.[49] This means that existing utility-scale solar facilities can generate about 20% of the annual electricity generated by the North Anna Nuclear Power Station on a similar area of disturbed land. These estimates however do not consider the differing land impacts and buffer requirements for each energy generation source.

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[48] U.S. Energy Information Administration *Electricity Generation and Consumption Data (EIA-920)*

[49] U.S. Energy Information Administration *Capacity Factors for Utility Scale Generators (Table 6.07.B.)*

The total statewide acreage estimate for all of Virginia's solar facilities is heavily influenced by a few exceptionally large facilities. Of the 38 active solar facilities, 29 are between five (5) and 20 MW in capacity and collectively account for roughly 25% of the total statewide acreage. There are zero facilities between 20 and 50 MW. Nine (9) facilities are above 50 MW in capacity and collectively account for about 75% of all land currently dedicated to solar facilities in Virginia. The two largest facilities in Virginia account for about 38% of all the land in the state currently dedicated to solar facilities. The influence of the state's largest facilities is likely to grow as the 300 MW Pleinmont Solar project in Spotsylvania County is expanded to 500 MW. New projects such as the approved 280 MW Pulaski County Solar project will also have a significant impact on the statewide total amount of impacted land in the state.

Table 6. *Share of Solar Facilities by Generating Capacity and Acres*

Generating Capacity	Number of Active Facilities	Share of Total Acreage	Share of Total Capacity
5-20 MW	29	25.1%	31.3%
20-50 MW	0	0.0%	0.0%
50-75 MW	1	2.4%	3.3%
75-100 MW	6	34.6%	35.8%
>100 MW	2	37.9%	29.5%

Although the state's largest solar facilities make up a significant portion of all impacted land, they are not more efficient based on the acres of land required to generate a megawatt of electricity. Regardless of size, both the disturbed site area and solar panel area share a linear relationship with megawatt generating capacity. While there is some variation and outliers as seen in *Figures 12* and *13*, the state's largest solar facilities use land at roughly the same rate as smaller solar facilities. With correlation coefficients close to a value of one (1), both the disturbed area and panel footprint area have a strong linear relationship with megawatt capacity. This suggests that a higher generating capacity is not more efficient from a land use perspective. Moreover, this also demonstrates that larger solar facilities do not have proportionally less disturbed land given the amount of electricity that is generated.

Figure 12. *Relationship Between Disturbed Site Area and Megawatt Capacity*

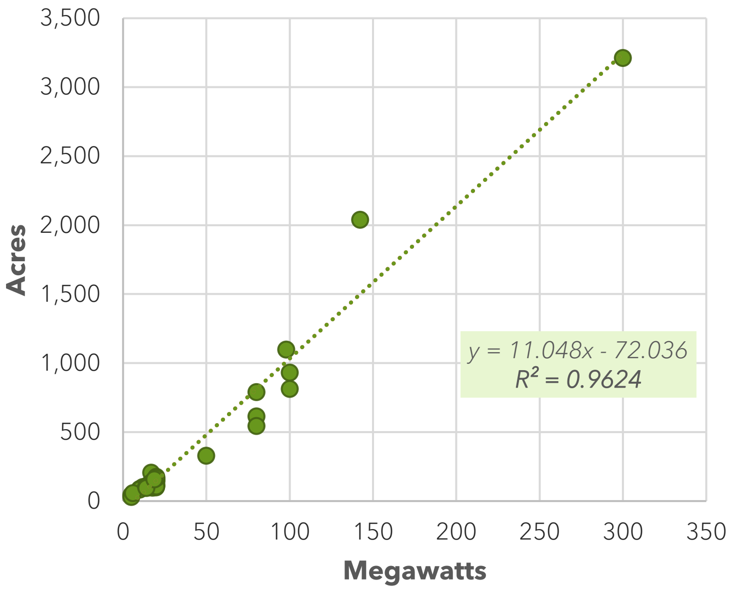
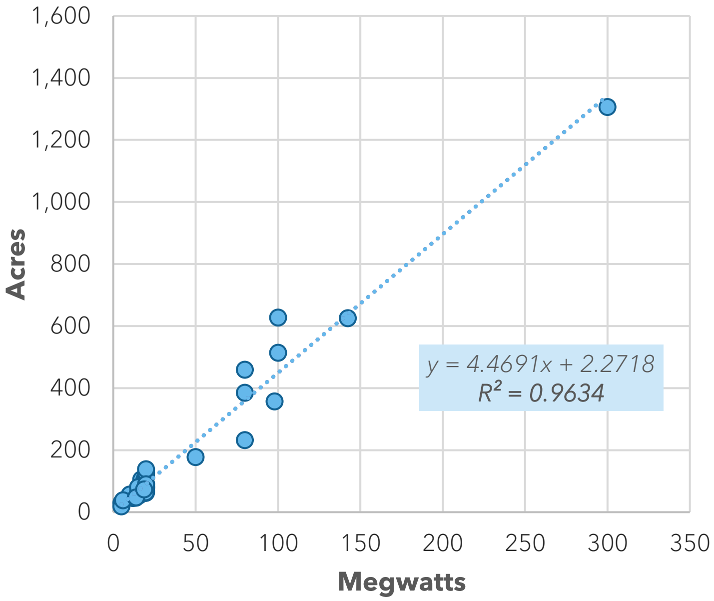


Figure 13. *Relationship Between Panel Footprint Area and Megawatt Capacity*



4.3 | Land Cover and Land Use Change

Based on the Virginia Statewide Land Cover Dataset (VaLCD), Virginia's 38 active solar facilities have primarily disturbed agriculture and forested land uses. A similar analysis based on the 2016 and 2006 National Land Cover Datasets (NLCD) is in Appendix B and largely confirms the findings from the VaLCD.

Previous forested land covers (Forest, Tree, and Harvested/Disturbed) account for 62.9% of all land currently used for solar facilities. The Forest classification specifically accounts for the most land cover change (58.1%). While this suggests that forested land is most likely to be impacted, these findings are influenced by a few data outliers (*see Figures 16 and 17*). Therefore, the results of this

Table 7. *Solar Facility Land Impacts by Land Cover Classification*

Land Cover Classification	Total Acres	Total Percent	Facility Average
Forest	8,035.1	58.1%	38.0%
Cropland	3,443.8	24.9%	45.9%
Pasture	966.2	7.0%	5.7%
Harvested/Disturbed	471.2	3.4%	3.0%
NWI/Other	327.6	2.4%	0.7%
Shrub/Scrub	231.5	1.7%	0.6%
Tree	194.6	1.4%	2.6%
Turf/Grass	134.0	1.0%	3.1%
Impervious	30.9	0.2%	0.5%
Open Water	6.7	0.0%	0.1%
Barren	0.0	0.0%	0.0%

Virginia Land Cover Dataset

Primary Land Cover Classifications

Forest

- *Forest*- Areas of at least 30% canopy cover of woody vegetation and **more** than one (1) acre in size.
- *Tree*- Areas of at least 30% canopy cover of woody vegetation and **less** than (1) acre in size.
- *Harvested/Disturbed*- Areas of forest clear cut or temporary clearing of vegetation.

Agriculture

- *Cropland*- Areas with vegetation planted or managed for production of food, feed, or fiber.
- *Pasture-* Areas of grasses and legumes for livestock grazing or production of seed or hay.

Herbaceous

- Shrub/Scrub- Woody vegetation with stems less than 6 meters tall
- *Turf/Grass*- Grasses planted in developed settings for aesthetic or erosion purposes as well as natural grass lands.

Wetlands

- *NWI/Other*- Areas with at least 25% vegetation that is periodically saturated with water.

analysis do not mean that all or even most solar facilities in Virginia are built on forested land. For example, the Gloucester Solar facility pictured in *Figure 14* is on a site that was mostly cropland. The Facility Average column in *Table 7* is a normalized land cover change measurement of individual facilities.

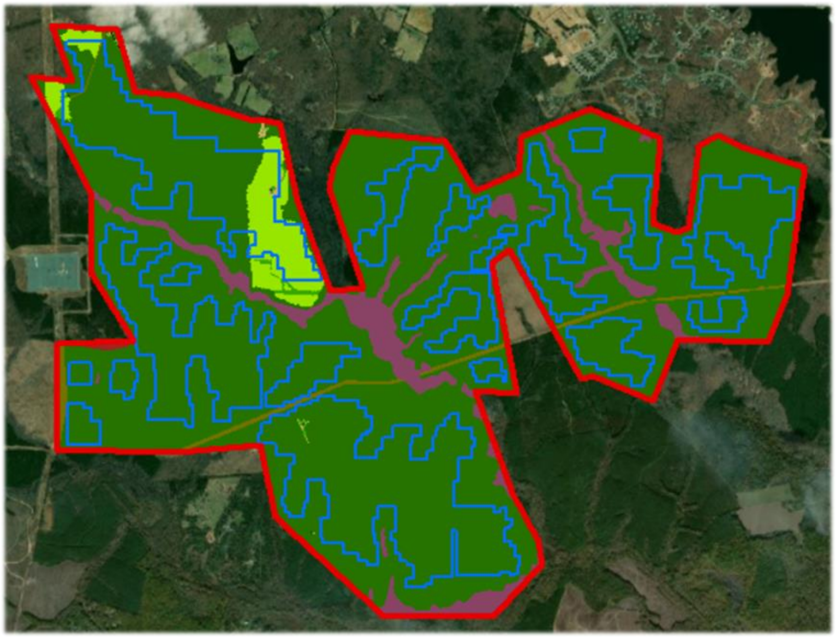
Agriculture land (Cropland and Pasture) equals 31.9% of the land disturbed by solar facilities. The Cropland classification specifically equals about 25% of the total statewide land use. Pastures equal the remaining 7.0% of agricultural land used by solar facilities. The remaining land covers (Herbaceous, Shrub/Scrub, Wetlands, Impervious, Barren, and Water) collectively account for only 5.2% of the total disturbed area of solar facilities.

When land cover change is analyzed statewide based on individual solar facilities and not by the total statewide combined area, a slightly different trend emerges. This helps to normalize outliers like the 300 MW Pleinmont Solar and the 142 MW Colonial Trail West Solar facilities which are much larger, and both occupy sites that were more than 85% forested *(See Figure 15)*. After normalizing each solar facility regardless of size, the average land cover type of a solar facility was about 46% Cropland and 38% Forest. This means that an individual solar facility in Virginia is more likely to be sited on cropland than on forest land. Nevertheless, there is still a high level of variation between the land cover changes of individual solar facilities.

Figure 14. *Land Cover of Gloucester Solar, Gloucester County, VA*

**Cropland: 96.8%, Tree: 3.2%*

Figure 15. *Land Cover of Pleinmont Solar, Spotsylvania County, VA*



**Forest: 88.4%, NWI: 5.9%, Pasture: 3.6%, Shrub/Scrub: 1.4%*

Although the two largest solar facilities in the state occupy mostly forested lands, there does not appear to be enough data to conclude that facility size is correlated with a specific land cover type. As shown in *Figures 16* and *17*, solar facilities up to 100 MW in capacity occupy sites with a wide range of cropland and forest land covers. However, as more large solar facilities over 100 MW in capacity are developed in Virginia this should be updated to determine if very large solar facilities continue to be sited in heavily forested areas.

Figure 16. *Share of Cropland Land Cover Impacted by Each Solar Facility*

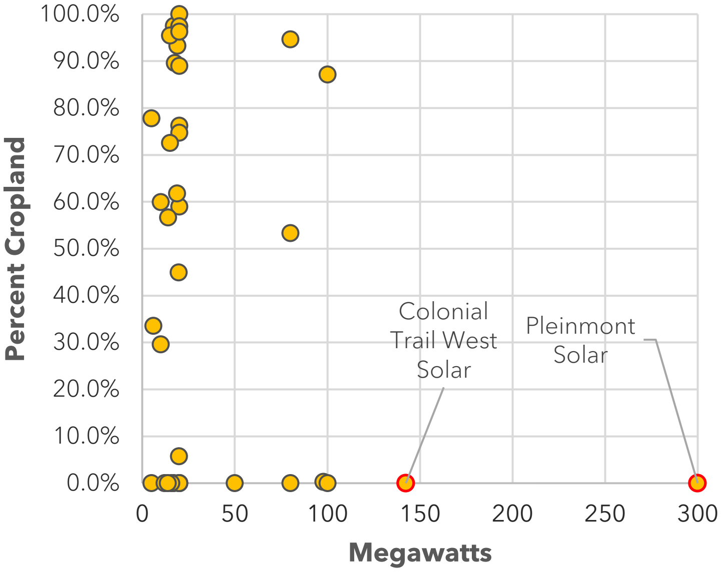
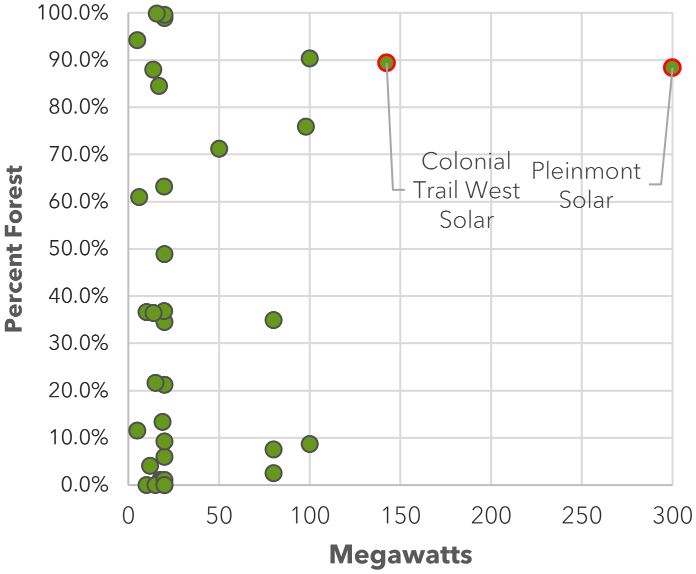


Figure 17. *Share of Forest Land Cover Impacted by Each Solar Facility*



While there are some facilities occupying sites with multiple previous land cover types, most facilities (*26 of 38*) occupy a site with a single land cover type accounting for at least 75% of the total disturbed site area. *Figure 18* reaffirms that individual solar facilities have been more often located on sites that were mostly cropland. Although the total statewide area of solar facilities was more heavily forested due to the influence of the state's largest facilities, there have been fewer total facilities constructed on heavily forested sites. This is an important distinction which means that more individual solar facilities occupy cropland, but more of the combined total acreage of all solar facilities was forested.

Figure 18. *Number of Solar Facilities by Primary Impacted Land Cover Type (>75%)*

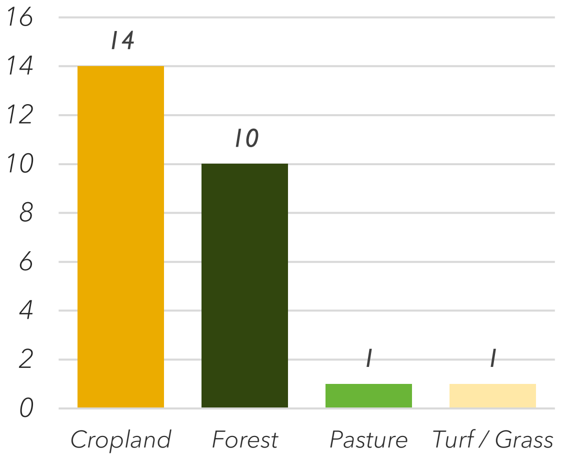
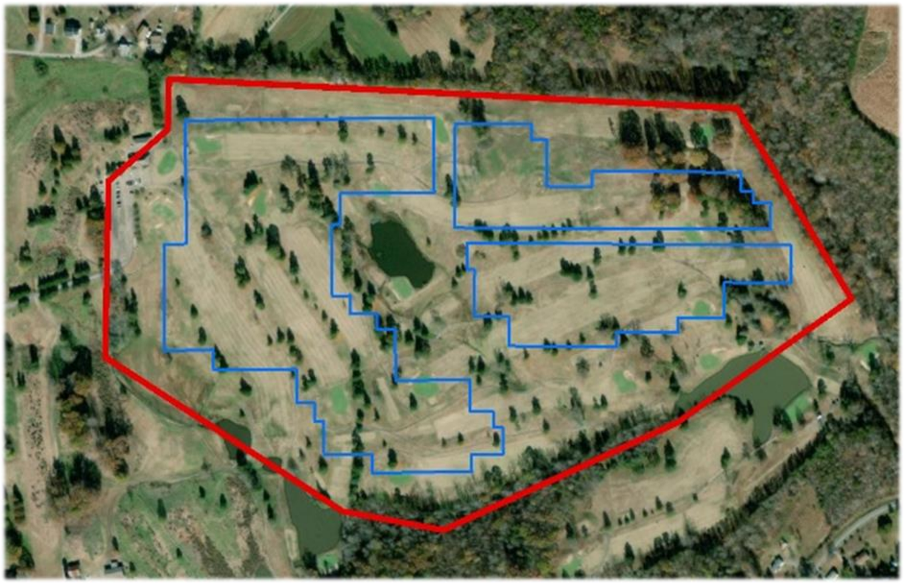


Figure 18 also presents two unique examples of specific solar facilities in Virginia that occupy sites with a single land cover type that was neither cropland nor forest. A third facility also occupies a site that was 68% pastureland. These three solar facilities pictured below represent the only three facilities in Virginia that do not occupy sites with a majority (>50%) of forested land, cropland, or a combination of both. Grasshopper Solar is an 80 MW facility located on a site previously used as pastureland for grazing. Clarke Solar (10 MW), which is the only solar facility in extreme Northern Virginia was also primarily pastureland. As previously noted, the Pasture classification includes both lands for grazing and natural grasslands. Finally, Danville Solar (12 MW) was mostly classified as Turf/Grass because of its location on an old golf course. This site was the only facility in this analysis that appeared to occupy a previously disturbed site that was used for a different active use.

Figure 19. *Land Cover of Danville Solar, Pittsylvania County, VA*

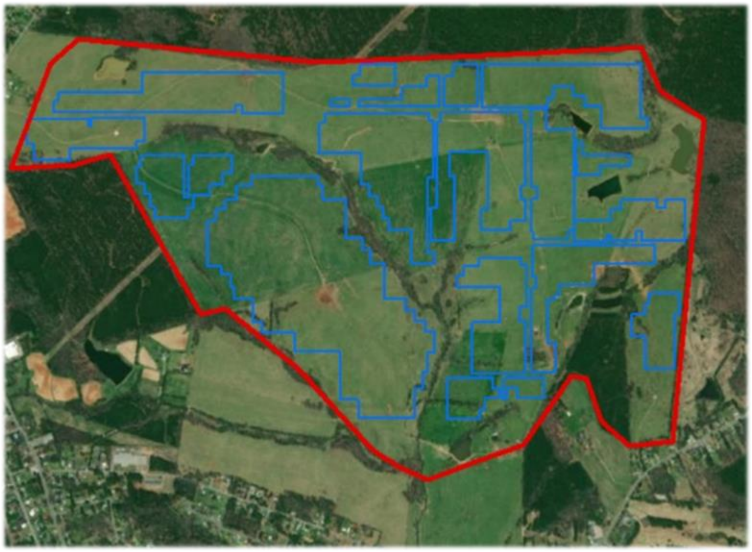


**Turf/Grass: 72.9. %, Tree: 21.1%, Forest: 4.1%*

Figure 20. *Land Cover of Clarke Solar, Clarke County, VA*

**Pasture: 67.5%, Cropland: 29.7%,*

Figure 21. *Land Cover of Grasshopper Solar, Mecklenburg County, VA*



**Pasture: 82.6%, Forest: 7.7%, Tree: 7.6%, Shrub/Scrub: 1.4%*

4.4 | Forested Lands

Since forest and agricultural lands are most likely to be impacted by solar facilities, it is important to further analyze the type and quality of these land cover types. Accordingly, this section focuses on the overall conservation value of forested land that has been used for solar facilities, while the next section analyzes the quality and suitability of cropland that has been converted into solar facilities.

Figure 22. *Distribution of Forest Conservation Values of Forest Land Impacted by Solar Facilities*

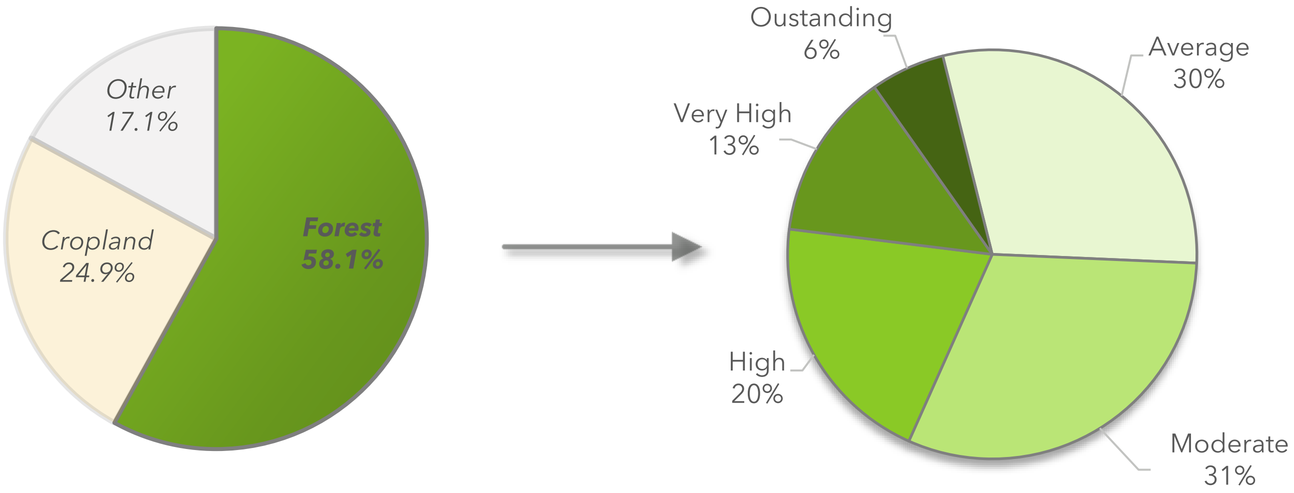


Table 8. *Forest Conservation Values of Forests Impacted by Solar Facilities Compared to Statewide Distribution*

Classification	**Forests Impacted by Solar**	***All Virginia Forests***
Average	**29.6%**	19.5%
Moderate	**31.0%**	20.5%
High	**20.3%**	20.7%
Very High	**13.3%**	19.4%
Outstanding	**5.9%**	19.8%

Based on the Virginia Department of Forestry's Forest Conservation Model (FCV), the forested land that has been converted into solar facilities is less likely to be of the highest conservation value (Outstanding or Very High). The FCV Model identifies priority forestland by considering watershed integrity, size of forested blocks, connectivity and proximity to other conserved lands, the threat of conversion, and the presence of diminished tree species. The model equally distributes all Virginia forests into five categories with roughly 20% of all statewide forests within each category. By comparison, only 5.9% of the forest land used for solar facilities was rated Outstanding, and 13,3% was rated Very High. Instead, solar facilities have been more likely to convert forested lands with the two lowest categories of forest conservation values (Average and Moderate).

Although most solar facilities have not impacted forest lands with the highest conservation values, there are a few examples of solar facilities built primarily on forest land with the highest conservation values. This includes Scott I and II Solar (17/20 MW) in Powhatan County, Martin Solar (5 MW) in Goochland County, and Whitehouse Solar (20 MW) in Louisa County (*Table B4* in Appendix B). Interestingly, these four facilities are all located in Central Virginia in contiguous counties.

4.5 | Croplands

Next, the Virginia Agricultural Model from Virginia ConservationVision helps to isolate the quality of active croplands that have been used for solar facilities. Unlike the Forest Conservation Model that equally classifies forest land into five evenly distributed classifications, the Agricultural Model has five classifications with an unequal distribution of total land in each classification. Statewide, the Agricultural Model rates a larger proportion of farmland as highly suitable. This helps to explain the larger proportion of solar facilities built on highly suitable farmland. A complete description of the methodology of the Agricultural Model and each classification is located in Appendix B.

Figure 23. *Distribution of Farmland Suitability Values of Cropland Impacted by Solar Facilities*

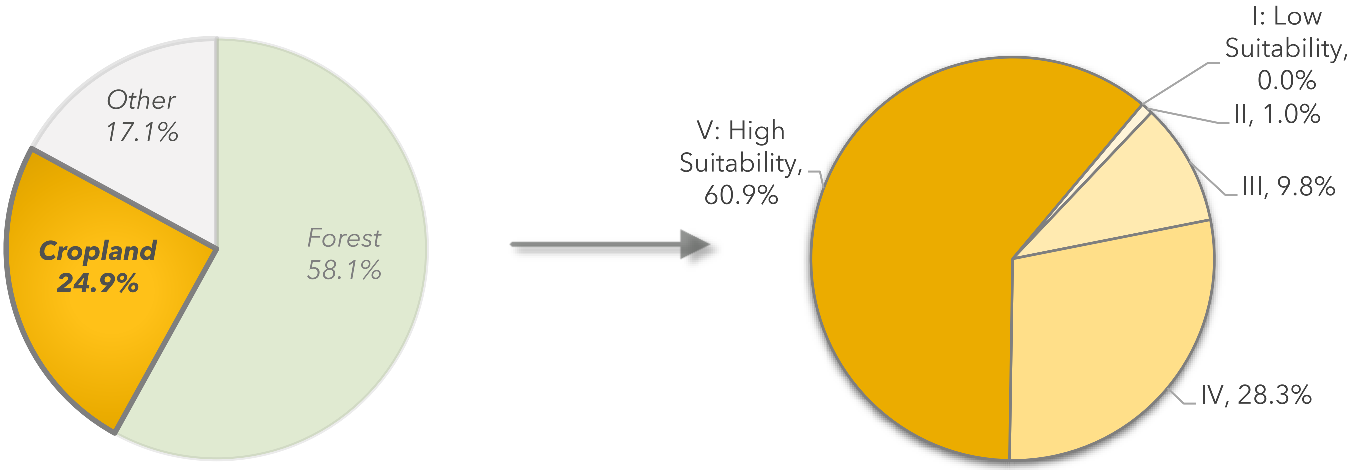


Table 9. *Farmland Suitability Values of Cropland Impacted by Solar Facilities Compared to Statewide Distribution*

Classification	Croplands Impacted by Solar	*All Virginia Croplands*
Class I: Low Suitability	**0.0%**	1.5%
Class II	**1.0%**	11.3%
Class III	**9.8%**	11.8%
Class IV	**28.3%**	39.3%
Class V: High Suitability	**60.9%**	36.1%

Table 10. *Soil Quality Score of Cropland Impacted by Solar Facilities*

Soil Quality Score	Croplands Used for Solar
Low: 0-20	**0.7%**
20-40	**3.4%**
40-60	**18.2%**
60-80	**20.6%**
High: 80-100	**57.0%**

Despite the difference in the methodology of the model, solar facilities still appear to be often built on croplands with the highest suitability classification. With close to 61% of the cropland used for solar facilities rated as highly suitable, solar facilities do appear to use a higher proportion of prime agricultural land. Currently, a total of six solar facilities are built on sites where most of the land (>75%) is rated as highly suitable (Class V) for agriculture. This includes Sappony Solar (20 MW) in Sussex County, Hollyfield Solar (17 MW) in King William County. Cherrydale Solar (20 MW) in Northampton County, Puller Solar (15 MW) in Middlesex County, Montross Solar (20 MW) in Westmoreland County, and Mechanicsville Solar (20 MW) in Hanover County. These facilities are mostly located in central and eastern Virginia where more fertile agricultural lands are present.

Several possible factors may help to explain the increased prevalence of siting solar facilities on cropland with high suitability. First, some of the qualities that make cropland highly suitable also make the land highly suitable for solar facilities. This may include climate, topography, accessibility, soil stability, and the size of a parcel. Many of these factors should be analyzed in more detail in the future.

To further assess the impact of solar facilities on agricultural lands, the National CropScape and Cropland Data Layer from the United States Department of Agriculture (USDA) was used to identify the types of crops cultivated on the impacted sites. Although this information changes annually, this analysis is based on the 2015 data layer and provides a basic insight into a single point in time. Based on this analysis, corn, soybeans, cotton, and wheat were the most common types of crops to be impacted. These disturbed areas account for only a very small proportion of all active cropland in the state. Corn and soybeans were the most impacted crops by solar facilities. These crops were also the most planted statewide both totaling over 450,000 acres (*Table 11*). Based on this analysis, cotton was impacted at a disproportionately high rate based on the total statewide acreage. Most of this cotton acreage comes from the Southampton Solar facility in Southampton County (388 acres) accounting for over half of all converted cotton cropland. Other culturally important crops to Virginia like tobacco and peanuts were not as widely impacted. There are likely several economic factors that help to explain these existing trends that should be explored in further detail as more facilities are built.

Table 11. *Types of Crops Grown on Croplands Impacted by Utility-Scale Solar Facilities*

Type of Crop	Disturbed Acres	Share of Disturbed Croplands	Total Statewide Planted Acres	Share of Statewide Croplands
Corn	914	*26.5%*	463,800	*29.6%*
Soybeans	870	*25.2%*	582,700	*37.2%*
Cotton	674	*19.6%*	83,800	*5.3%*
Double: Winter Wheat/Soybeans	410	*11.9%*	216,800	*13.8%*
Peanuts	165	*4.8%*	13,500	*0.9%*
Winter Wheat	78	*2.3%*	30,100	*1.9%*
Alfalfa	68	*2.0%*	23,500	*1.5%*
Potatoes	57	*1.7%*	3,300	*0.2%*
Sorghum	53	*1.6%*	10,300	*0.7%*
Tobacco	23	*0.7%*	8,600	*0.5%*
All Others (Each <0.5%)	106	*3.1%*	---	---
*Other Hay/ Non Alfalfa**	68	*2.0%*	23,500	---

**Other Hay/Non Alfalfa is not classified as cropland in the Virginia Land Cover Dataset. It is considered pastureland. The resulting 68 acres founds in this analysis of CropScape data is likely the result of inconsistencies between each dataset.*

4.6 | Demographics

In addition to the physical impacts of utility-scale solar facilities on land use, demographics are also a relevant component of development. The following research identifies the basic demographic factors of communities that are near operating solar facilities. This demonstrates what types of communities are bearing the burden of solar energy development or receiving the associated benefits that solar facilities may provide to landowners, local governments, and nearby residents. Household income and race are the two primary factors considered in this analysis. Information on population density, median house value, and poverty rate are also included.

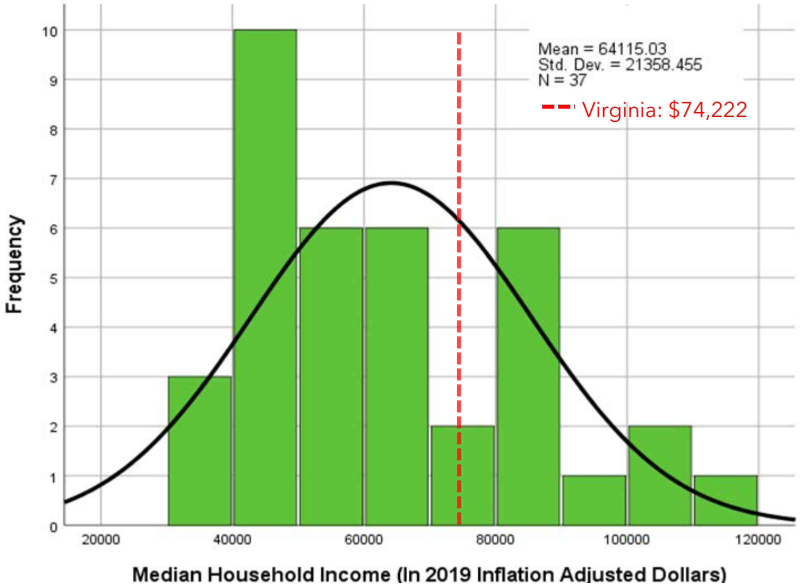
Household Income

Based on the income levels of census tracts where solar facilities are present, existing solar facilities in Virginia are in areas with a wide variety of income levels from as low as $35,000 up to about $120,000. Based on the Virginia average median household income of $74,222, a larger portion of utility-scale solar facilities are sited in areas that are predominantly middle and low-income (*Figure 24*). A total of twelve (12) facilities are located in census tracts with median household incomes that exceed the statewide average. There are 25 facilities located in census tracts with household income levels below the statewide average. Communities with a household income level between $40,000 and $50,000 are the most common (10) census tract with a solar facility. The communities with lower median household income levels are also more likely to have larger solar facilities. This means that a larger share of electricity generation from solar facilities is taking place in lower-income areas (*Table 12* and *Figure 25*).

An important component of these findings is that solar facilities are primarily located in rural areas where income levels are often lower than Virginia's more densely populated areas. The availability and cost of land are a driver of the locations of solar facilities that may also be associated with household income levels in the area. This however does not mean that solar facilities in Virginia are not also located in areas of high income. The state's largest solar facility (Pleinmont Solar in Spotsylvania County) by both acreage and megawatts is in the census tract with the highest median household income of any census tract with a solar facility.

Figure 24. *Distribution of Solar Facilities by Median Household Income*

*Oceana Solar is in a census tract that does not report MHI



ACS 2019 Census Tracts

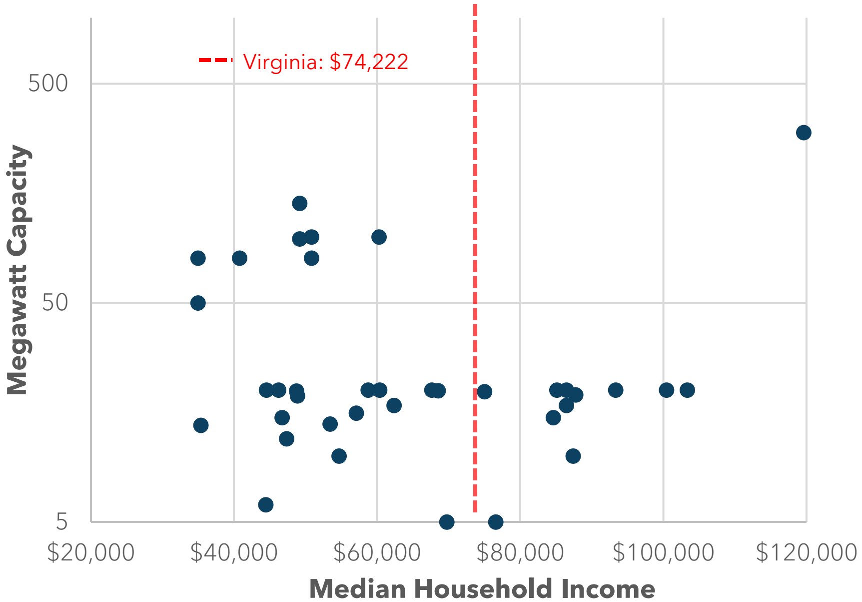
Table 12. *Distribution of Solar Facilities by Median Household Income*

Median Household Income	Total Facilities	Total MW	Share of Statewide Generation (MW)
< $40,000	3	144	9.7%
$40,000-$59,999	16	672	45.3%
$60,000-$79,999	8	207	13.9%
$80,000-$99,999	7	121	8.2%
≥ $100,000	3	340	22.9%

ACS 2019 Census Tracts

Although Pleinmont Solar in Spotsylvania County is an outlier as a large facility in a high-income area, it does appear that most of Virginia's largest (>50 MW) solar facilities have been located in areas with lower household incomes. The solar facilities in Virginia with capacities up to 20 MW have been constructed in communities of varying income levels (*Figure 25*). There are no facilities between 20 and 50 MW in Virginia. However, of the nine (9) facilities larger than 50 MW, eight of them are located in census tracts with median household incomes at or below $60,000. This is well below the statewide average of $74,222. This suggests an emerging trend where larger solar facilities are being located in lower-income areas. This trend is preliminary and will require further analysis as more solar facilities are built. However, these findings do substantiate the importance of creating beneficial siting agreements that allow local governments and nearby residents to maximize the benefits available through siting agreements to improve local quality of life, particularly in distressed and low-income communities.

Figure 25. *Solar Facility Size Compared to Local Median Household Income*

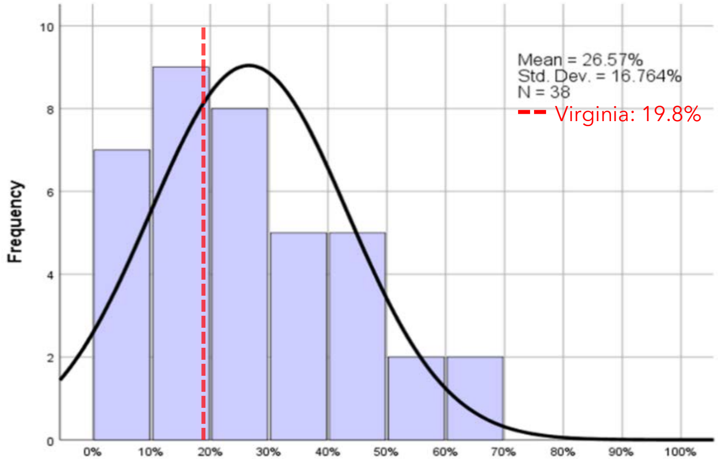


ACS 2019 Census Tracts

Race

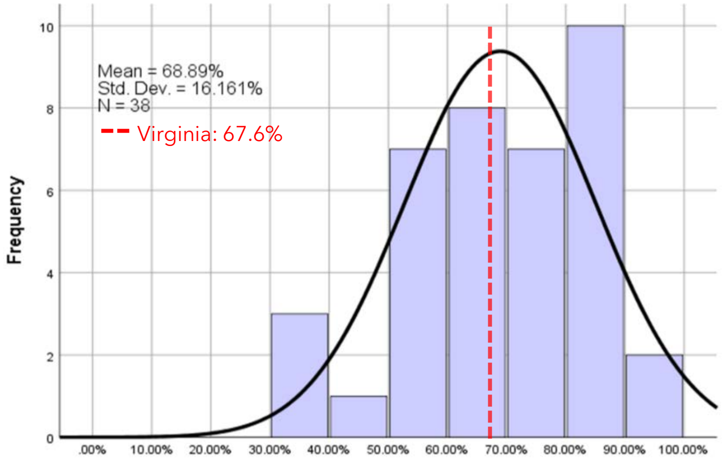
Like income, there are a few notable trends based on the percentage of the population by race in the communities where solar facilities are located. To date, solar facilities have been built in areas with a very small minority population as well as other areas with a relatively high minority population. However, based on the total average (26.6%), solar facilities have been slightly more likely to be in areas with an African American population greater than the statewide average of 19.8% (*Figure 26*). By comparison, the average percent White population of census tracts with solar facilities was 68.9% compared to the state average of 67.7% (*Figure 27*). A total of 22 solar facilities (out of 38) are in census tracts with an African American population above the statewide average. Additionally, four (4) solar facilities have been built in areas with an African American population greater than 50%. Moreover, the siting of solar facilities is far less common in areas with significant populations of all other races. This is likely the result of demographic patterns in rural Virginia that consists primarily of White and African American populations.

Figure 26. *Distribution of Solar Facilities by Black or African American Population of Nearest Census Tract*



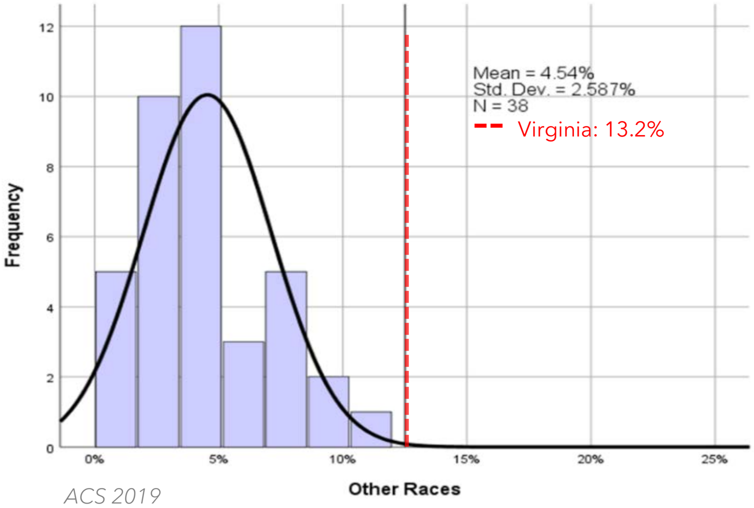
ACS 2019

Figure 27. *Distribution of Solar Facilities by White Population of Nearest Census Tract*



ACS 2019

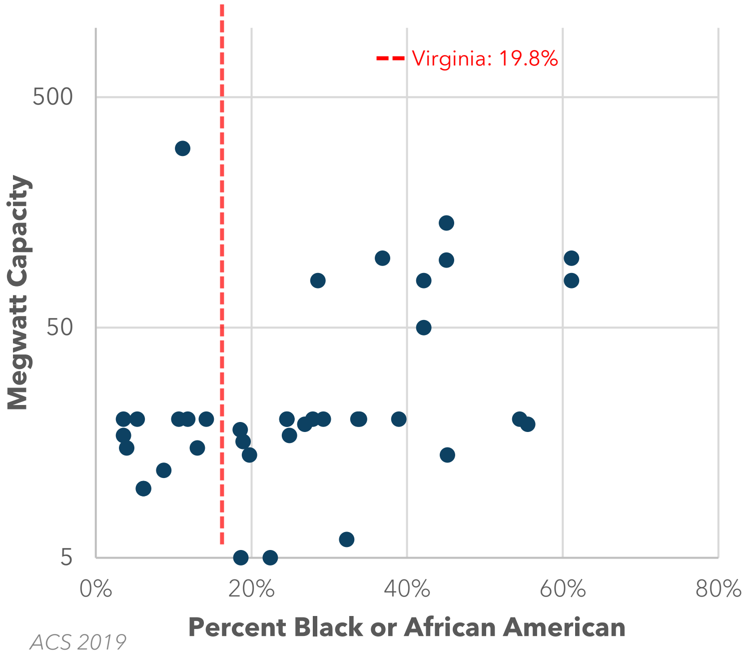
Figure 28. *Distribution of Solar Facilities by Population of Other Races of Nearest Census Tract*



ACS 2019

Similar to household income, it does appear that most of Virginia's largest solar facilities are located in census tracts with a relatively high African American population. The Pleinmont Solar facility in Spotsylvania County is the only exception to this trend. All other solar facilities over 50 MW in size are in census tracts with an African American population that is greater than 25%. Further analysis will be necessary to identify potential explanations for this pattern and to understand the potential impacts and benefits of solar development on minority populations.

Figure 29. *Solar Facility Size Compared to Percent African American Population of Nearest Census Tract*



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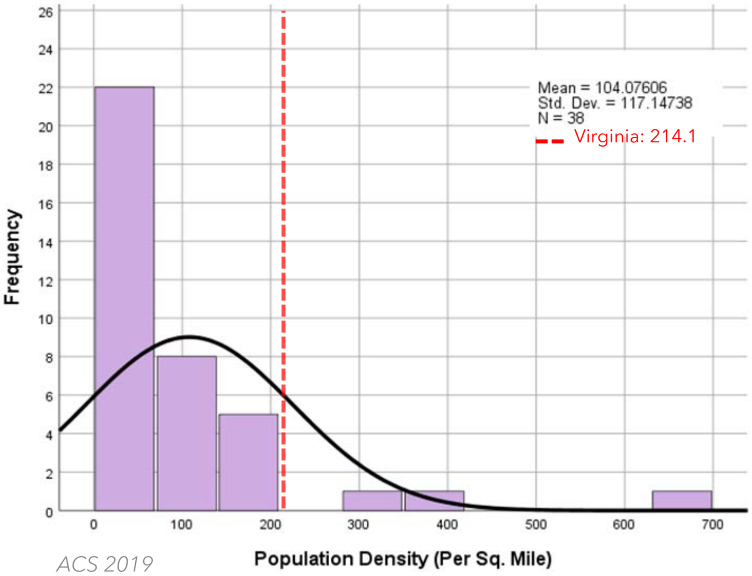
Additional Demographic Factors

In addition to income and race, there are a few additional demographic factors that provide further insight into the development patterns of utility-scale solar facilities. First, the data on population density indicates that solar facilities are typically located in less dense rural areas. Most solar facilities are in census tracts with less than 50 people per square mile. Given the total land requirements for solar facilities, the population density of surrounding communities will likely continue to remain relatively low. The solar facilities in Fauquier County, Henrico County, and Virginia Beach City are the only sites that have been built in census tracts with population densities that exceed that statewide average (*Figure 30*).

Figure 30. *Distribution of Solar Facilities by Population Density of Nearest Census Tract*



ACS 2019

Both the median house value and the poverty rate of communities with solar facilities are similar to the household income findings. Overall, solar facilities are less likely to be built in locations with very high median house values and are more likely to be built in areas with higher poverty rates. While both vary widely, the comparison of the average to the statewide average provides a useful comparison (*Figures 31* and *32*). The local poverty rate should be carefully considered in siting agreements of new solar facilities to ensure that they actively contribute to and improve the quality of life for residents.

Figure 31. *Distribution of Solar Facilities by Median House Value of Nearest Census Tract*

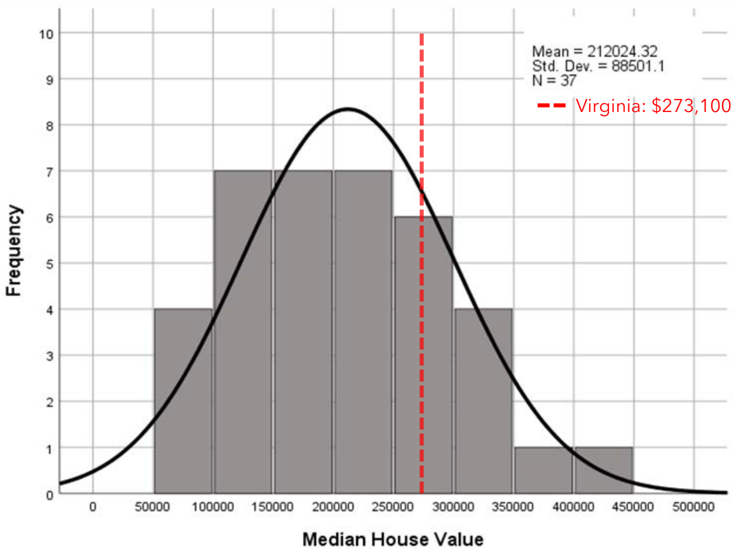


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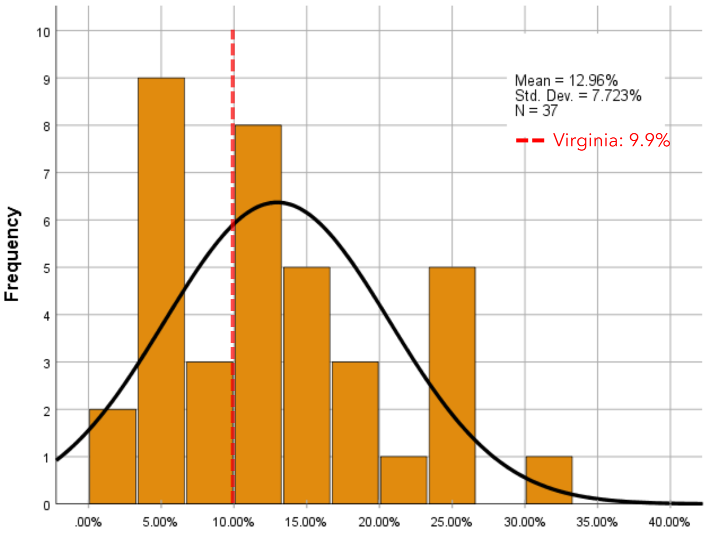
Figure 32. *Distribution of Solar Facilities by Poverty Rate of Nearest Census Tract*

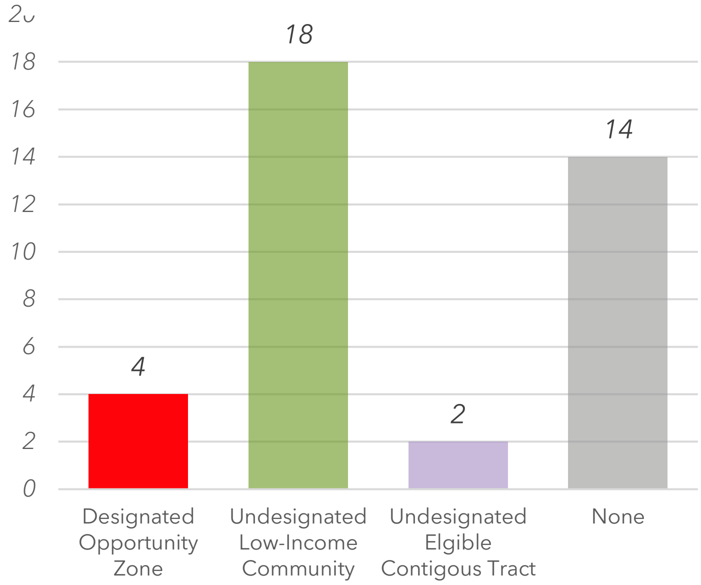


ACS 2019

Opportunity Zones

Currently, only four (4) solar facilities are located in census tracts that are designated as Opportunity Zones. An additional 18 facilities are located in census tracts that are undesignated low-income communities that qualify for an opportunity zone designation. This is an important distinction given the economic incentives and benefits available to both developers and local communities choosing to site solar facilities in opportunity zones.

Figure 33: *Solar Facilities in Officially Designated Census Tracts*



4.7 | Best Practices

Through the passage of the Virginia Clean Economy Act in 2020, Virginia made an important step in joining a host of other states that have committed to a transition to 100% clean energy. This is a major decision that includes overcoming several hurdles to fully realize a future that is free of carbon emissions. Many other states have already taken steps to renewable energy that are transferable to the implementation of solar energy in Virginia.

First, expanding the quantity and quality of public information available on the rapidly expanding implementation of renewable energy is critical to promoting transparency and supporting further analysis on the subject. To date, many government agencies have struggled to maintain comprehensive data on the rapid expansion of solar energy. Compiling and updating this information provides a basis for eliminating misconceptions and identify policy priorities. Accordingly, some states have already begun to develop and publish informative datasets focused on the implementation of solar infrastructure. Agencies like the California Energy Commission, the Maryland Energy Administration, and the New York State Energy Research have published information on the size and location of all solar facilities in the state.[50] Other nonprofits like the North Carolina Sustainable Energy Association have partnered with public agencies to collect basic information on the size and location of solar facilities.

However, the state of New Jersey stands out for its committed effort to consistently update and publish solar development information. This includes comprehensive geospatial information on the size, location, and boundaries of all solar facilities greater than one (1) MW. Within the State of New Jersey's Board of Public Utilities, the Office of Clean Energy has established the New Jersey Clean Energy Program to promote renewable energy. This includes the Solar Activity Report which is published monthly that provides detailed information for all solar projects that are installed and currently under development in New Jersey.[51] The report categorizes all installed and planned solar projects in the state and routinely updates their status of development. Furthermore, this information is provided to the Department of Environmental Protection's Climate Change, Clean Energy, and Sustainability Element to create various GIS data layers related to solar. This includes the physical boundaries of all PV solar facilities greater than one (1) MW classified as either grid supply installations or behind-the-meter installations.[52] This data was collected in a manner similar to the methods used in this research based on aerial and live satellite information.

Ultimately, this information should also be compiled in a comprehensive national database. The United States Wind Turbine Database (USWTDB) offers a foundation for creating a similar database of all solar energy infrastructure in the United States. The database is constantly updated with accurate geospatial information through a collaboration between the U.S. Department of Energy, the U.S. Geologic Survey, the American Clean Power Association, and the Electricity Markets and Policy Group. A similar collaboration for solar energy facilities to properly understand the larger development impacts nationwide will be an important component of promoting their sustainable development in the coming years.

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[50] https://www.nyserda.ny.gov/All-Programs/Programs/NY-Sun/Solar-Data-Maps/Statewide-Projects, https://ww2.energy.ca.gov/sitingcases/solar/index_cms.html

[51] https://njcleanenergy.com/renewable-energy/project-activity-reports/project-activity-reports

[52] https://www.state.nj.us/dep/aqes/gisdownloads.html

5.0 | Conclusion

This research has explored several factors related to the recent development of utility-scale solar facilities in Virginia. Understanding the impacts and opportunities of the historical placement of solar facilities is critical to avoiding future land use conflicts and supporting Virginia's energy and decarbonization goals. The development of utility-scale solar facilities like many other methods of electricity generation is a land-intensive process with real impacts on local communities. This research characterizes some of these impacts and provides a foundation for future analysis and policy considerations. It also substantiates the role that local and regional planners have in the siting decisions of utility-scale projects and their influence on the future of energy generation in Virginia.

Virginia's 2050 clean energy goal and its deployment of solar energy is a necessary, appropriate, and attainable goal consistent with statewide management policies and practices. However, as Virginia continues to encourage utility-scale solar development, it is important to contextualize the current development patterns and impacts of solar development to inform better land use practices. Specifically, the land use of existing utility-scale solar installations in rural areas primarily on forested and agricultural land demonstrates the high degree of connectedness and interdependence between the land use and activity of urban and rural areas. This is not a new occurrence unique to solar development. Rural areas have long held a critical role in providing consumption goods such as food, energy, raw materials, and labor to urban areas. The recent development of solar facilities in rural areas is just a new example of this relationship. As Virginia's most populated areas grow and demand more energy, the interests of natural rural areas must be carefully considered to realize a sustainable energy future. The findings and recommendations in this research are guided by this need to balance local land use interests with larger statewide renewable energy goals.

Finding this balance between local land use interests and renewable energy goals substantiates the role of planners in a clean energy future. The widespread deployment of solar energy facilities has led to the intersection of energy planning and land use planning unlike ever before. Given the prevalence and size of new solar facilities occupying land in many of Virginia's localities, local planners will be directly involved in numerous siting decisions. The challenges and opportunities that solar facilities present in local communities demonstrate the outsized role that local planning will have on the clean energy future in Virginia.

Additionally, this discussion of utility-scale solar facilities is part of a much larger transition occurring in Virginia and worldwide to mitigate the harmful impacts of fossil fuel energy generation. The development of utility-scale solar facilities is not independent of efforts to reduce energy use, integrate local distributed solar systems into the urban fabric, and promote other renewable energy sources. While utility-scale solar is an important source of affordable and reliable renewable energy, it is only one of many components of Virginia's clean energy future. As planners, policymakers, researchers, and developers consider land use regulations to guide the development of solar facilities, they must also recognize their role in simultaneously supporting other activities that can reduce local energy use and incorporate energy generation into the built environment.

Finally, while the findings of this research have clarified some uncertainties about the impacts of utility-scale solar across Virginia, it has also exposed many more topics, questions, and concerns that should be explored in the future. The dataset created for this research has significant value for continuing to assess and characterize the potential impacts of solar development. This research has simply investigated some of the most pressing topics related to the development of solar facilities, but there remain many unexplored factors that this dataset may help to explain. This data should be explored, updated, and shared to fully understand all the relevant impacts and ongoing trends. For this reason, this research simply serves as a foundation for further research and analysis.

6.0 | Recommendations

Based on the analysis and research into the existing land use and development trends of solar facilities in Virginia, a list of recommendations is provided below to help encourage the sustainable development of solar energy facilities. The specific goals and objectives are oriented towards continuing to assess the related impacts of solar facilities while also planning new solar energy systems that reduce potential conflicts with land use while also expanding access and opportunity. Specifically, the recommendations in this plan build upon the overarching pursuit of sustainable development. The methods and findings of this research establish a foundation for continuing to track the development of utility-scale solar facilities. The findings also reveal new areas of interest and concern that should be further evaluated. Finally, this research provides the necessary context to promote policy guidance and development strategies that more fully balance environmental, social, and economic sustainability interests.

The recommendations of this plan are intended for the Virginia Department of Mines, Minerals, and Energy and are informed by the results of this research. However, the findings and recommendations for this plan are also informative and useful for a variety of stakeholders. The sustainable development of solar energy facilities in Virginia will ultimately be a collaborative process and the following recommendations are intended to complement the ongoing work of numerous stakeholders across the state.

6.1 | List of Recommendations

Vision: Virginia has abundant solar energy to sustainably power the Commonwealth for generations. Proper energy and land use planning can minimize the unfavorable impacts of solar energy development while fully maximizing the benefits and opportunities of the widespread deployment of solar energy facilities.

Goal 1: Ensure that Virginia's transition to clean energy and specifically solar is consistently tracked, documented, and accessible.

Objective 1.1: Develop and maintain a comprehensive dataset on the implementation of solar energy infrastructure across Virginia.

a. Reference new statewide aerial photography from the Virginia Base Mapping Program to confirm and update the exact location and boundaries of existing solar facilities.

b. Establish a consistent criterion for data updating and entry that follows a scalable framework.

c. Publish a GIS data layer available for public access quarterly that includes the boundaries and attributes of all solar facilities greater than 1 MW in Virginia.

d. Create an online mapper displaying basic information on the location, size, and attributes of existing solar facilities.

e. Coordinate with entities outside Virginia to establish a national database on solar infrastructure similar to the U.S. Wind Turbine Database (USWTDB) hosted by the United States Geologic Survey (USGS).

Objective 1.2: Collaborate with other state agencies to expand the quality and quantity of available information.

a. Work with the Department of Environmental Quality (DEQ) to update the Permit by Rule (PBR) application requirements to include a digitized vector GIS layer of solar site boundaries and solar panel footprint.

b. Build and update a queryable database that relates state land cover, land use, conservation, and demographic information collected by other agencies with the locations of solar facilities.

c. Partner with the Department of Conservation and Recreation to update the ConserveVirginia dataset to better accommodate the ongoing implementation of solar infrastructure across rural areas.

Objective 1.3: Partner with academic and non-profit researchers to improve the accuracy of the data and determine new topics for additional tracking.

a. Offer research grants to researchers to conduct large quantitative analyses on siting data.
b. Compile and evaluate the relevant siting factors of battery storage units associated with utility-scale solar facilities.

Objective 1.4: Provide local and state decision-makers with the data tools and appropriate analysis to inform policymaking.

a. Improve the Virginia Solar Energy Development and Energy Storage Authority Annual Report by including maps and other spatial information that show the most common areas of existing and recent solar development across the state.

b. Coordinate with the DEQ and SCC to create and publish an annual report on land use trends of solar development.

Goal 2: Fully evaluate the drivers and impacts of solar energy facility siting throughout Virginia.

Objective 2.1: Study the specific economic factors of landowners, developers, and corporate and public energy buyers that have driven the development of utility-scale solar facilities.

a. Review ownership and leasing records of parcels with utility-scale solar facilities that consider previous activity on developed lands.

b. Explore the impacts of land leasing and sale costs on the location and size of solar facilities.

c. Study the business models associated with different sized utility-scale solar facilities, and how that might influence land use and demographic impacts.

d. Support greater access to transmission line data and information on sub-station access to help further analyze the drivers that determine the location of future development.

Objective 2.2: Identify specific sites to monitor local land impacts such as microclimates, soil moisture, temperature, runoff, and wildlife access.

Objective 2.3: Explore possible patterns and trends of subcategories of utility-scale solar facilities in Virginia.

a. Based on UVA Cooper Center's classification of Demographic Regions, explore land use and siting patterns of solar facilities specific to different regions in the state.

b. Compare data of county-specific development trends with local zoning ordinances, comprehensive plans, and local regulatory processes to evaluate the influence and impact of local regulations.

Goal 3: Promote strategies to help offset and mitigate any existing and expected negative land use impacts.

Objective 3.1: Advocate for the colocation of utility-scale solar facilities that maintain productive farm uses within active solar site areas.

a. Review the latest research on agrivoltaics and agriphotovoltaics (APV) to understand the viability of crop production and grazing in and around solar facilities.

b. Work with the Virginia Department of Conservation and Recreation (DCR) to expand the Virginia Pollinator Smart Program.

Objective 3.2: Establish guidance and incentives to discourage widespread solar development on prime farmlands or forest conservation areas.

a. Partner with the DEQ and DCR to establish criteria for preferable solar siting locations based on the locations of prime farmland, rare habitats, and important forests.

b. Maintain the agricultural use assessment on solar sites when proper strategies such as size limitation, colocation, percent of project area, and soil quality guidance are followed.

Goal 4: Develop policy guidance and incentives that capitalize on viable underutilized, disturbed, and degraded lands and maximize quality of life benefits to local communities.

Objective 4.1: Work with policymakers to incentivize solar development on brownfields, degraded lands, abandoned mined land AML) sites, parking canopies, and concentrated animal operation feeding operations (CAFOs).

a. Create a project-based award to encourage solar energy production in areas of best use.

b. Help localities to offer loan guarantees or low-interest loans for the development of brownfields for solar energy purposes.

Objective 4.2: Upgrade DMME and DEQ information on brownfields and make it more accessible to solar developers.

Objective 4.3: Assess environmental justice siting impacts.

a. Set a target to ensure communities most affected by air, land, or water pollution receive the benefits of state spending on programs, grants, and investments in solar energy.

b. Allocate workforce training funds for solar energy jobs that benefit communities of color and historically economically disadvantaged communities.

c. Support tax credits for renewable energy investment in economically distressed areas.

d. Integrate data on environmental justice communities from EPA EJ Screen and the Greenlink Equity Map with mapping efforts of solar facilities.

6.2 | Implementation

Executing these recommendations will require multiple actors and partnerships to fully realize the potential of utility-scale solar in Virginia. The four main goals in this plan cover different topics and are not necessarily iterative. Therefore, the implementation schedule below outlines a separate phased approach for each goal. The schedule is categorized into *short-term* (0-3 years), *mid-term* (3-5 years), *long-term* (5-10+ years), and *ongoing*.

Goal 1

Expanding the quantity, quality, and availability of data related to the development of utility-scale solar facilities in Virginia is an immediate need. Improving access to this data represents an important step in being able to fully understand the potential land use impacts of utility-scale solar in Virginia. However, this goal requires a substantial amount of work and collaboration with a variety of entities to properly track the size, location, and impact of utility-scale solar infrastructure in Virginia and nationwide. In addition to the DMME, the DEQ, DCR, federal agencies, other state energy agencies, non-profits, universities, and solar developers will all be important contributors to a robust and accurate dataset tracking the implementation of solar facilities.

	Short Term	Mid Term	Long Term	Ongoing
1.1 Maintain dataset on solar development	■	■	■	■
1.1: a) Update GIS Layers	▒	▒	▒	▒
1.1: b) Establish consistent data collection processes	▒			
1.1: b) Publish GIS layer of active solar facilities	▒			
1.1: c) Create online mapper on solar development		▒		
1.1: d) Assist in creation of a national dataset on solar			▒	
1.2 Collaborate with state agencies	■	■	■	
1.2: a) Update DEQ's PBR application requirements	▒	▒		
1.2: b) Build database of land impacts		▒	▒	
1.2: c) Update ConserveVirginia			▒	
1.3 Partner with universities and non-profits	■	■	■	
1.3: a) Develop research grants	▒	▒		
1.3: b) Gather info on battery storage	▒			
1.4 Inform policymakers	■	■	■	■
1.4: a) Improve Annual Solar Report	▒			
1.4: b) Create annual report on land use		▒		

Goal 2

Expanding the knowledge and research on both the impacts and benefits of utility-scale solar facilities will also require extensive collaboration outside of the DMME. In addition to agencies like DEQ and DCR, fully understanding the impacts of solar facilities will also require the inclusion of local governments, landowners, developers, and community members to fully assess local factors related to the development of utility-scale solar facilities.

	Short Term	Mid Term	Long Term	Ongoing
2.1 Study economic factors	■	■		
2.1: a) Review property history	▨			
2.1: b) Explore land sale and leasing information	▨	▨		
2.1: c) Study developer business models		▨		
2.1: d) Support access to transmission and substation data	▨			
2.2 Conduct case studies of specific solar facilities		■	■	■
2.3 Evaluate classifications of solar facilities	■	■		
2.3: a) Study development patterns by region	▨			
2.3: b) Compare development with local land use policy		▨		

Goal 3

Promoting strategies to actively mitigate potential impacts of utility-scale solar development will require creative strategies that include working with local and state policymakers to develop policies and tax incentives to influence the ideal types of development.

	Short Term	Mid Term	Long Term	Ongoing
3.1 Advocate for colocation	■			
3.1: a) Literature review of agrivoltaics	▨			
3.1: b) Promote VA Pollinator Smart Program	▨			
3.2 Protect farmland and forests		■	■	
3.2: a) Establish siting criteria near sensitive lands		▨		
3.2:b) Maintian land use assessment for proper siting		▨	▨	

Goal 4

Finally, maximizing the benefits of utility-scale solar development emphasizes distributing the benefits and burdens of solar development to the most appropriate locations.

	Short Term	Mid Term	Long Term	Ongoing
4.1 Incentivize development on distrubed land	■	■		
4.1: a) Provide financial benefit to proper siting	▨			
4.1: b) Loan gurantees/low-interest loans		▨		
4.2 Upgrade availibilty of data on brownfields	■	■		
4.3 EJ siting impacts	■	■		
4.3: a) Create target for investment	▨			
4.3: b) Allocate workfore training funds		▨		
4.3: c) Support tax credit in distressed areas		▨		
4.3: d) Integrate solar with EJ mapping tools		▨		

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Appendix A: Methods

Data Sources

Virginia Land Cover Dataset

Created by the Virginia Geographic Information Network (VGIN), the Virginia Land Cover Dataset is a 12-classification scheme of statewide land use at a 1-meter resolution. The dataset was released in 2016 and is largely based on VGIN orthophotography from 2011 to 2015. The dataset also relies on a variety of state and national geospatial datasets to refine the classification scheme. The statewide dataset is very large and therefore is divided into tiled imagery and is available in both raster and vector format. For this analysis, the vector format was used.

Classifications:

Water
- 11 – Open Water

Developed
- 21 – Impervious Extracted
- 22 – Impervious External
- 31 – Barren

Forested
- 41 – Forest
- 42 – Tree

Shrubland
- 51 – Shrub/Scrub

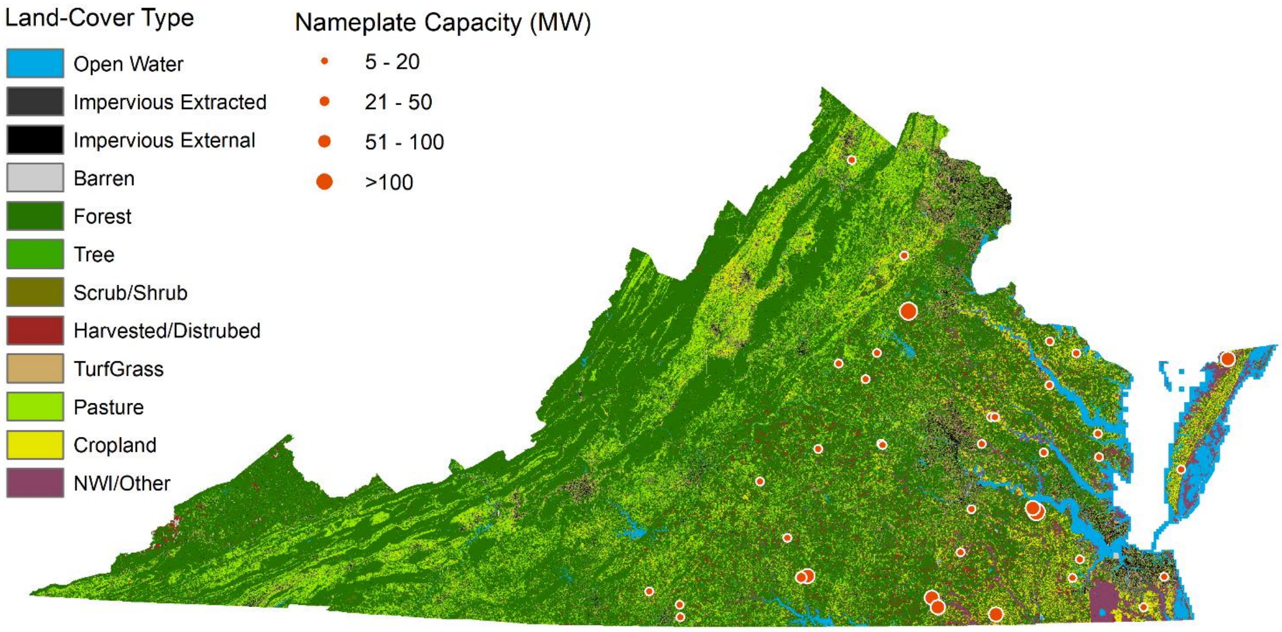
Disturbed
- 61 – Harvested/Disturbed

Herbaceous
- 71 – TurfGrass

Planted/Cultivated
- 81 – Pasture
- 82 – Cropland

Wetlands
- 91 – NWI/Other

Figure A1. *Virginia Land Cover Dataset with Solar Overlay*



For a complete description of the methodology of this dataset and a description of each classification, please review the Technical Plan of Operations in the link below.

https://www.vita.virginia.gov/media/vitavirginiagov/integrated-services/pdf/LandCover_TechnicalPlanOfOperations_v7_20160506.pdf

Forest Conservation (FCV) Model

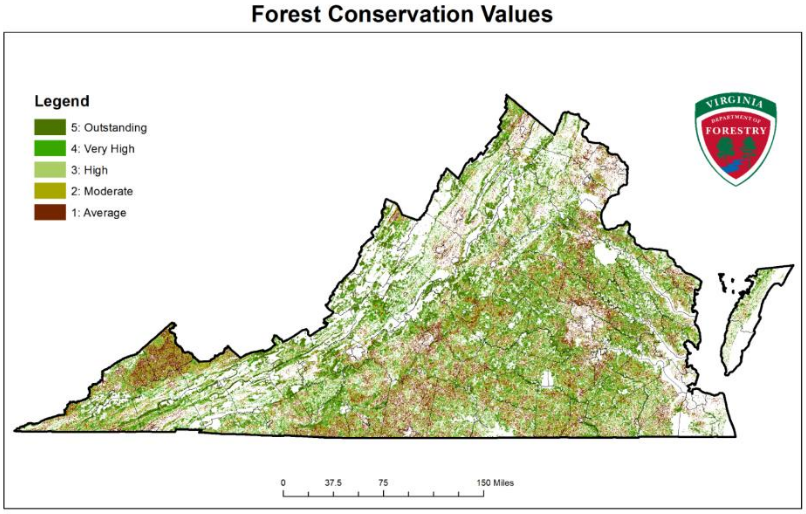
The Forest Conservation Value (FCV) model is a tool designed by the Virginia Department of Forestry (VDOF) to identify the highest priority forestland for conservation in Virginia. The model was created in 2013 and later refined in 2017. The model is available in raster format at a 30-meter resolution. The model ranks all forestland in Virginia from 1 (lowest) to 5 (highest). Six key components are considered in the model: Forested Blocks, Forest Management Potential, Connectivity, Watershed Integrity, Threat of Conversion, and Significant Forest Communities and Diminished Tree Species

Classifications:

- *1: Average*
- *2: Moderate*
- *3: High*
- *4: Very High*
- *5: Outstanding*

https://www.dcr.virginia.gov/natural-heritage/vaconvisforest

Figure A2. *Virginia FCV Model*



Virginia Agricultural Model

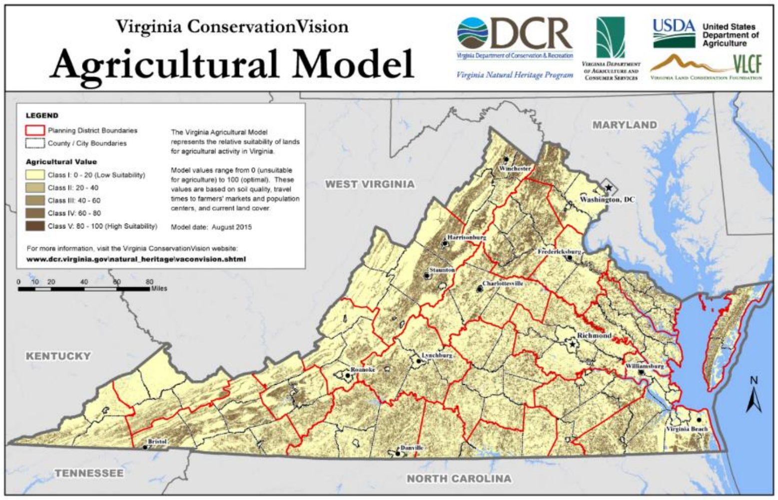
The Virginia Agricultural Model created by the Virginia Department of Conservation and Recreation's Virginia Natural Heritage Program in 2015 quantifies the relative suitability of lands for agricultural activity across the state. It is a raster dataset at a 30-meter resolution that ranks the agricultural value of lands ranges from 0 (unsuitable) to 100 (optimal). Agricultural value is assessed primarily based on inherent soil suitability, but also accounts for current land cover as well as travel time between agricultural producers and consumers. Soil suitability includes information from the gSSURGO geodatabase and the National Commodity Crop Productivity Index.

Classifications:

- *0-20 (Low Suitability)*
- *20-40*
- *40-60*
- *60-80*
- *80-100 (High Suitability)*

https://www.dcr.virginia.gov/natural-heritage/vaconvisagric

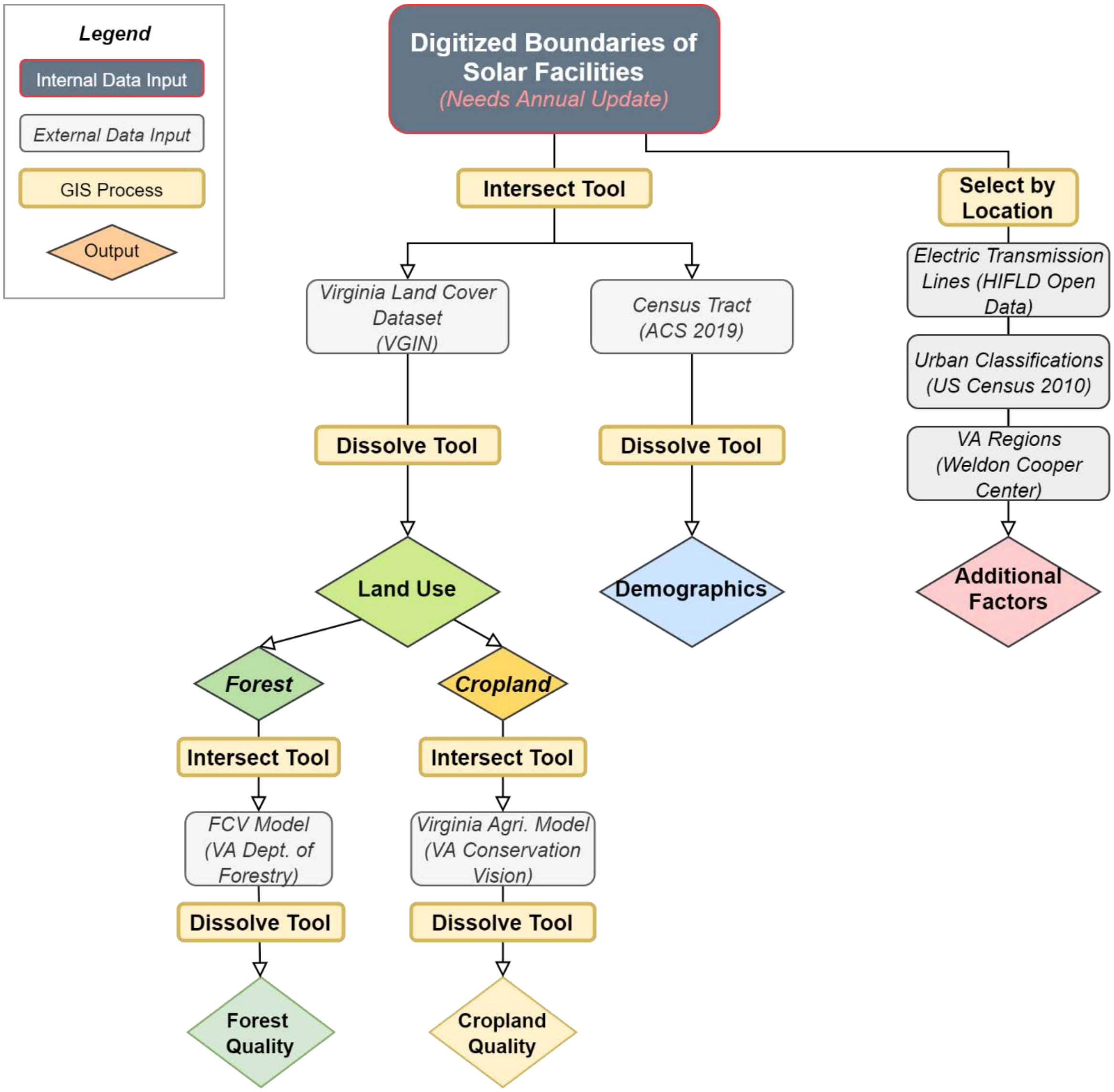
Figure A3. *Virginia Agricultural Model*



Workflow

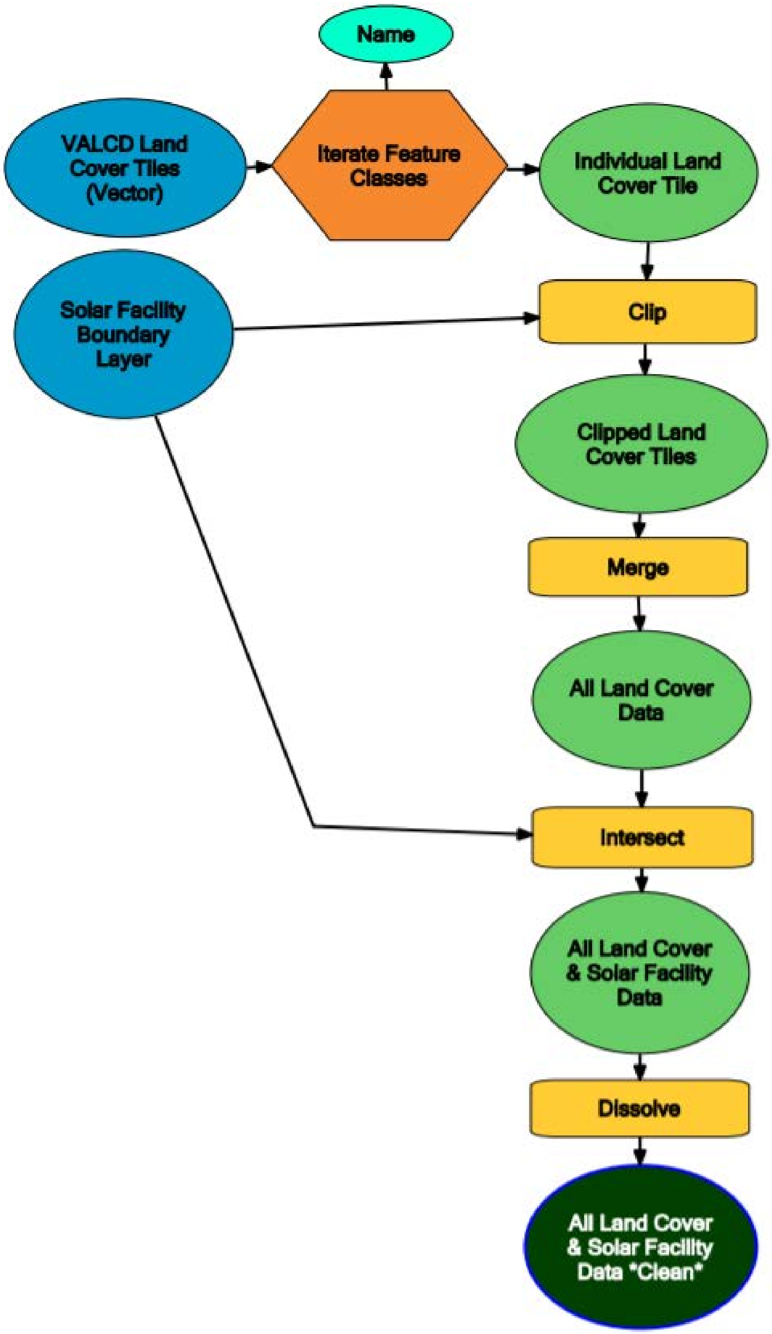
The workflow of the GIS analysis conducted in this research is diagrammed in the figure below. This information is presented to ensure that this analysis is easily replicable as more solar facilities are added across the state in the coming years. The diagram details the data input used and the GIS geoprocessing tools used in ArcMap to conduct this analysis. The process used to extract land use information is simplified in this diagram. The full workflow of extracting land cover change using ModelBuilder is shown on the next page. The continual update of the boundaries of new solar facilities and the revisions to the boundaries of existing solar facilities will be a major task necessary to refine and expand the findings of this research.

Figure A4. *Workflow of GIS Analysis of Solar Facility Land Use*



The figure below details the workflow used in the ArcMap ModelBuilder to analyze the land use of solar facilities based on the Virginia Land Cover Dataset. Since the land cover dataset is large and split into hundreds of tiles, ModelBuilder helps to automate the geoprocessing of this dataset to match the boundaries of each solar facility in Virginia.

Figure A5. *Diagram of ArcMap ModelBuilder Used to Analyze Land Use*



Appendix B: Results

NLCD Findings

National Land Cover Database (NLCD) data serves as a supplement to the Virginia Land Cover dataset which was the primary dataset used in this analysis. Since NLCD data has been used in similar analyses of solar facilities conducted in the United States, it was included in the analysis as a comparison to the results of other studies that were discussed in the methodology section. NLCD data is at a lower resolution (30-meter resolution) than the Virginia Land Cover data (1-meter resolution) and therefore was not considered for the primary component of this research. NLCD data is collected every five (5) years, while the Virginia Land Cover data has only been published once in 2016, so the NLCD data also provided a greater understanding of land cover change across time. Ultimately, the NLCD data uses a different methodology, classification system, and larger raster resolution, which provides slightly different results. Nevertheless, it offers a useful comparison to affirm many of the research findings from the Virginia Land Cover dataset.

Table B1. *Solar Facility Land Cover Change (NLCD Data)*

NLCD 2006 Total Change	
Forest	45.44%
Cultivated Crops	25.33%
Shrub/Scrub	10.59%
Hay/Pasture	7.23%
Herbaceuous	6.32%
Wetlands	2.93%
Developed	2.04%
Open Water	0.11%
Barren Land	0.01%

NLCD 2016 Total Change	
Forest	37.68%
Cultivated Crops	28.93%
Herbaceuous	14.06%
Hay/Pasture	7.28%
Shrub/Scrub	6.45%
Wetlands	3.26%
Developed	2.29%
Open Water	0.04%
Barren Land	0.01%

Full Research Findings Results

The full tabular results of the GIS analysis discussed in the research findings are presented on the next four (4) pages. This includes the total disturbed and solar footprint acreages for the 38 solar facilities in operation in Virginia as of January 2021. It also includes the results on land cover change, quality of forest land impacted, and quality of cropland impacted represented as percentages for each solar facility. In some cases, these estimates represent the site area of an individual solar facility as of January 2021 and may not represent the final project area upon the completion of construction or expansion projects. This information should be updated frequently. This information is also available in spreadsheets for additional analysis and manipulation.

Table B2. *Background Information for Operating Solar Facilities in Virginia as of January 2021*

Name	MW	County	Service Date	Panel Area (Acres)	Distrubed Site Area (Acres)
Eastern Shore Solar	80	Accomack	2016-12	459.5	613.9
Scott Solar	17	Powhatan	2016-12	105.6	206.4
Woodland Solar	19	Isle of Wight	2016-12	106.1	145.6
Whitehouse Solar	20	Louisa	2016-12	84.2	160.2
Clarke Solar	10	Clarke	2017-07	51.5	87.2
Remington Solar	20	Fauquier	2017-10	78.8	114.7
Correctional Solar	20	New Kent	2017-11	63.1	153.0
Sappony Solar	20	Sussex	2017-11	92.5	147.1
Buckingham Solar	19.8	Buckingham	2017-11	62.3	116.7
Cherrydale Solar	20	Northampton	2017-11	114.2	163.2
Oceana Solar	17.6	Virginia Beach City	2017-12	62.3	96.2
Scott-II Solar	20	Powhatan	2017-12	70.0	111.6
Essex Solar	20	Essex	2017-12	125.9	174.9
Southampton Solar	100	Southampton	2017-12	628.3	813.6
Palmer Solar	5	Fluvanna	2017-12	30.3	43.2
Martin Solar	5	Goochland	2017-12	19.0	29.2
Kentuck Solar	6	Pittsylvania	2018-05	38.9	57.7
UVA Hollyfield Solar	17	King William	2018-09	73.4	134.2
Puller Solar	15	Middlesex	2018-10	64.8	114.5
Montross Solar	20	Westmoreland	2018-12	81.3	106.5
Gloucester Solar	19.9	Gloucester	2019-04	79.1	133.3
Colonial Trail West Solar	142	Surry	2019-12	626.2	2039.4
Rives Road Solar	19.7	Prince George	2020-05	64.4	98.4
Myrtle Solar	15	Suffolk City	2020-06	81.5	111.9
Pamplin Solar	15.7	Appomattox	2020-07	53.8	110.3
Grasshopper Solar	80	Mecklenburg	2020-07	385.5	790.2
Hickory Solar	20	Chesapeake City	2020-08	138.4	150.9
Mechanicsville Solar	20	Hanover	2020-09	90.1	166.5
Spotsylvania Solar	300	Spotsylvania	2020-09	1306.9	3211.0
Irish Road/Whitmell Solar	10	Pittsylvania	2020-10	57.7	83.8
Spring Grove I Solar	97.9	Surry	2020-10	357.9	1096.8
Danville Solar	12	Pittsylvania	2020-11	46.2	100.9
Greensville County Solar	80	Greensville	2020-12	232.5	544.0
Twittys Creek Solar	13.8	Charlotte	2020-12	46.5	103.3
Gardy's Mill Solar	14	Westmoreland	2020-12	47.9	93.5
Briel Farm Solar	18.8	Henrico	2020-12	74.1	157.0
Sadler Solar	100	Greensville	2021-01	514.3	931.5
Bluestone Solar	50	Mecklenburg	2021-01	177.7	329.4

Table B3. *Solar Facility Land Cover Change (Virginia Land Cover Dataset)*

Name	MW	County	Open Water	Impervious	Barren	Forest	Tree	Shrub/ Scrub	Disturbed	Turf/ Grass	Pasture	Crop land	NWI/ Other
Bluestone Solar	50	Mecklenburg	0.0%	0.1%	0.0%	71.3%	5.7%	6.0%	0.0%	0.0%	16.7%	0.0%	0.2%
Briel Farm Solar	18.8	Henrico	0.0%	0.6%	0.0%	13.4%	7.4%	0.0%	0.0%	2.9%	12.7%	61.8%	1.2%
Buckingham Solar	19.8	Buckingham	0.0%	0.0%	0.0%	63.2%	0.6%	0.0%	27.6%	2.7%	0.0%	5.8%	0.0%
Cherrydale Solar	20	Northampton	0.6%	0.0%	0.0%	21.3%	1.2%	0.0%	0.0%	1.7%	0.0%	74.8%	0.4%
Clarke Solar	10	Clarke	0.0%	0.6%	0.0%	0.0%	1.6%	0.0%	0.0%	0.7%	67.5%	29.6%	0.0%
Colonial Trail West Solar	142.4	Surry	0.0%	0.1%	0.0%	89.4%	0.2%	3.6%	2.6%	0.1%	0.8%	0.0%	3.3%
Correctional Solar	20	New Kent	0.0%	0.5%	0.0%	98.9%	0.3%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%
Danville Solar	12	Pittsylvania	0.7%	1.2%	0.0%	4.1%	21.1%	0.0%	0.0%	72.9%	0.0%	0.0%	0.1%
Eastern Shore Solar	80	Accomack	0.0%	0.8%	0.0%	2.5%	0.7%	0.0%	0.8%	0.5%	0.0%	94.6%	0.0%
Essex Solar	20	Essex	0.0%	0.1%	0.0%	34.5%	5.9%	0.0%	0.0%	0.4%	0.0%	59.0%	0.0%
Gardy's Mill Solar	14	Westmoreland	0.0%	1.7%	0.0%	36.4%	1.9%	0.0%	0.0%	3.3%	0.0%	56.7%	0.0%
Gloucester Solar	19.9	Gloucester	0.0%	0.0%	0.0%	0.0%	3.2%	0.0%	0.0%	0.0%	0.0%	96.8%	0.0%
Grasshopper Solar	80	Mecklenburg	0.6%	0.1%	0.0%	7.6%	7.7%	0.0%	0.0%	0.0%	82.6%	0.0%	1.4%
Greensville County Solar	80	Greensville	0.0%	0.6%	0.0%	35.0%	0.2%	0.9%	7.3%	0.6%	1.1%	53.4%	1.1%
Hickory Solar	20	Chesapeake City	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%
Irish Road/Whitmell Solar	10	Pittsylvania	0.0%	0.4%	0.0%	36.7%	0.5%	0.0%	0.0%	2.5%	0.0%	60.0%	0.0%
Kentuck Solar	6	Pittsylvania	0.0%	0.0%	0.0%	61.0%	2.1%	0.0%	0.0%	3.3%	0.0%	33.6%	0.0%
Martin Solar	5	Goochland	0.0%	0.0%	0.0%	94.2%	0.0%	0.0%	0.0%	0.0%	5.7%	0.0%	0.0%
Mechanicsville Solar	20	Hanover	0.0%	0.9%	0.0%	0.0%	1.4%	0.0%	0.0%	1.4%	0.0%	96.3%	0.0%
Montross Solar	20	Westmoreland	0.0%	0.8%	0.0%	1.1%	0.1%	0.0%	0.0%	0.6%	0.0%	97.4%	0.0%
Myrtle Solar	15	Suffolk City	0.0%	2.0%	0.0%	0.0%	1.4%	0.0%	0.0%	1.1%	0.0%	95.4%	0.0%
Oceana Solar	17.6	Virginia Beach City	0.0%	0.0%	0.0%	1.1%	0.0%	0.0%	0.0%	0.5%	0.0%	89.6%	8.7%
Palmer Solar	5	Fluvanna	0.0%	0.6%	0.0%	11.6%	9.7%	0.0%	0.0%	0.0%	0.4%	77.8%	0.0%
Pamplin Solar	15.7	Appomattox	0.0%	0.0%	0.0%	99.9%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
Puller Solar	15	Middlesex	0.0%	0.7%	0.0%	21.6%	4.4%	0.0%	0.0%	0.7%	0.0%	72.6%	0.0%
Remington Solar	20	Fauquier	0.0%	0.0%	0.0%	6.0%	7.1%	0.1%	0.0%	0.3%	9.7%	76.2%	0.5%
Rives Road Solar	19.7	Prince George	0.0%	1.1%	0.0%	36.9%	4.1%	0.0%	0.0%	12.7%	0.0%	45.0%	0.2%
Sadler Solar	100	Greensville	0.0%	0.1%	0.0%	90.4%	0.0%	0.3%	6.8%	0.0%	0.8%	0.0%	1.7%
Sappony Solar	20	Sussex	0.0%	0.0%	0.0%	9.2%	0.5%	0.0%	1.2%	0.0%	0.0%	89.0%	0.1%
Scott Solar	17	Powhatan	0.0%	0.2%	0.0%	84.6%	1.2%	0.0%	12.9%	1.2%	0.0%	0.0%	0.0%
Scott-II Solar	20	Powhatan	0.0%	0.1%	0.0%	99.6%	0.1%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%
Southampton Solar	100	Southampton	0.0%	0.1%	0.0%	8.7%	0.4%	0.0%	3.6%	0.0%	0.0%	87.2%	0.0%
Spotsylvania Solar	300	Spotsylvania	0.0%	0.0%	0.0%	88.4%	0.3%	1.4%	0.2%	0.1%	3.6%	0.0%	5.9%
Spring Grove I Solar	97.9	Surry	0.0%	0.1%	0.0%	75.9%	0.1%	7.3%	14.0%	0.1%	0.0%	0.3%	2.2%
Twittys Creek Solar	13.8	Charlotte	0.0%	0.5%	0.0%	88.0%	4.0%	3.2%	0.0%	4.1%	0.0%	0.0%	0.2%
UVA Hollyfield Solar	17	King William	0.0%	0.0%	0.0%	0.6%	0.5%	0.0%	0.0%	1.3%	0.0%	97.5%	0.1%
Whitehouse Solar	20	Louisa	0.0%	0.0%	0.0%	49.0%	0.8%	0.0%	37.0%	0.0%	13.2%	0.0%	0.0%
Woodland Solar	19	Isle of Wight	0.0%	2.5%	0.0%	0.7%	0.6%	0.0%	0.8%	2.2%	0.0%	93.3%	0.0%

Table B4. *Quality of Impacted Forest Land as Percent of Total Facility Disturbed Area (Virginia Department of Forestry Forest Conservation Values (FCV) Data)*

Name	MW	County	Average	Moderate	High	Very High	Oustanding
Bluestone Solar	50	Mecklenburg	61.9%	18.7%	1.4%	0.0%	0.0%
Briel Farm Solar	18.8	Henrico	2.1%	8.1%	0.6%	0.0%	0.0%
Buckingham Solar	19.8	Buckingham	2.5%	31.6%	49.4%	6.0%	0.0%
Cherrydale Solar	20	Northampton	9.2%	10.0%	1.0%	0.0%	0.0%
Clarke Solar	10	Clarke	0.0%	3.5%	0.0%	0.0%	0.0%
Colonial Trail West Solar	142.4	Surry	37.1%	39.2%	17.0%	2.1%	0.0%
Correctional Solar	20	New Kent	54.4%	37.6%	6.1%	0.1%	0.0%
Danville Solar	12	Pittsylvania	0.5%	0.7%	0.2%	0.0%	0.0%
Eastern Shore Solar	80	Accomack	2.8%	3.9%	0.5%	0.1%	0.0%
Essex Solar	20	Essex	23.6%	5.4%	0.0%	0.0%	0.0%
Gardy's Mill Solar	14	Westmoreland	3.9%	16.8%	7.7%	0.0%	0.0%
Gloucester Solar	19.9	Gloucester	1.5%	2.6%	0.0%	0.0%	0.3%
Grasshopper Solar	80	Mecklenburg	17.1%	8.1%	0.9%	0.2%	0.0%
Greensville County Solar	80	Greensville	20.6%	16.4%	5.9%	0.0%	0.0%
Hickory Solar	20	Chesapeake City	0.0%	0.0%	0.0%	0.0%	0.0%
Irish Road/Whitmell Solar	10	Pittsylvania	3.1%	0.0%	0.0%	0.0%	0.0%
Kentuck Solar	6	Pittsylvania	12.8%	47.1%	2.0%	0.0%	0.0%
Martin Solar	5	Goochland	2.3%	0.1%	6.4%	2.3%	73.3%
Mechanicsville Solar	20	Hanover	0.0%	0.0%	0.0%	0.0%	0.0%
Montross Solar	20	Westmoreland	1.2%	0.9%	0.0%	0.0%	0.0%
Myrtle Solar	15	Suffolk City	1.9%	0.0%	0.0%	0.0%	0.0%
Oceana Solar	17.6	Virginia Beach City	0.0%	0.0%	0.0%	0.0%	0.7%
Palmer Solar	5	Fluvanna	8.6%	1.2%	0.0%	0.0%	0.0%
Pamplin Solar	15.7	Appomattox	35.5%	48.8%	14.9%	0.0%	0.0%
Puller Solar	15	Middlesex	0.3%	8.4%	15.9%	0.5%	0.0%
Remington Solar	20	Fauquier	0.5%	0.2%	1.3%	0.8%	0.0%
Rives Road Solar	19.7	Prince George	35.5%	7.8%	0.0%	0.0%	0.0%
Sadler Solar	100	Greensville	14.2%	37.8%	27.1%	5.4%	0.0%
Sappony Solar	20	Sussex	5.3%	2.0%	1.3%	1.3%	0.0%
Scott Solar	17	Powhatan	0.0%	0.0%	0.2%	75.2%	24.6%
Scott-II Solar	20	Powhatan	0.0%	0.0%	0.3%	46.4%	53.0%
Southampton Solar	100	Southampton	6.6%	1.3%	0.1%	0.0%	0.0%
Spotsylvania Solar	300	Spotsylvania	12.3%	20.3%	26.1%	23.2%	11.5%
Spring Grove I Solar	97.9	Surry	44.6%	35.6%	11.6%	1.3%	0.0%
Twittys Creek Solar	13.8	Charlotte	54.6%	30.0%	11.2%	1.0%	0.0%
UVA Hollyfield Solar	17	King William	0.0%	0.1%	4.9%	0.2%	0.0%
Whitehouse Solar	20	Louisa	3.4%	1.0%	24.5%	59.3%	11.0%
Woodland Solar	19	Isle of Wight	0.0%	0.5%	1.2%	1.2%	0.2%

Table B5. *Quality of Impacted Cropland as Percent of Total Facility Disturbed Area (Virginia ConservationVision Agricultural Model Data)*

Name	MW	County	Class I	Class II	Class III	Class IV	Class V
Bluestone Solar	50	Mecklenburg	0.0%	0.7%	0.0%	1.1%	20.8%
Briel Farm Solar	18.8	Henrico	0.0%	0.0%	0.3%	35.9%	51.6%
Buckingham Solar	19.8	Buckingham	0.0%	0.0%	0.0%	10.8%	4.8%
Cherrydale Solar	20	Northampton	0.0%	0.0%	0.0%	1.8%	78.3%
Clarke Solar	10	Clarke	0.0%	9.4%	81.7%	2.6%	5.4%
Colonial Trail West Solar	142.4	Surry	0.0%	0.0%	0.1%	1.3%	2.9%
Correctional Solar	20	New Kent	0.0%	0.0%	0.0%	0.0%	0.0%
Danville Solar	12	Pittsylvania	0.0%	5.5%	0.7%	11.8%	20.9%
Eastern Shore Solar	80	Accomack	0.0%	0.1%	17.2%	32.4%	47.6%
Essex Solar	20	Essex	0.3%	0.4%	0.0%	2.5%	66.2%
Gardy's Mill Solar	14	Westmoreland	1.8%	0.0%	0.0%	65.4%	0.0%
Gloucester Solar	19.9	Gloucester	0.0%	0.0%	7.0%	90.8%	1.8%
Grasshopper Solar	80	Mecklenburg	0.1%	3.4%	18.3%	27.5%	44.4%
Greensville County Solar	80	Greensville	0.0%	2.2%	4.8%	0.2%	50.8%
Hickory Solar	20	Chesapeake City	0.0%	0.0%	0.0%	98.5%	0.0%
Irish Road/Whitmell Solar	10	Pittsylvania	0.0%	0.0%	0.0%	1.4%	73.8%
Kentuck Solar	6	Pittsylvania	0.0%	0.0%	0.0%	26.9%	16.4%
Martin Solar	5	Goochland	0.0%	0.0%	0.0%	5.4%	0.0%
Mechanicsville Solar	20	Hanover	0.0%	9.0%	5.6%	0.0%	85.4%
Montross Solar	20	Westmoreland	0.0%	1.0%	0.5%	4.4%	89.3%
Myrtle Solar	15	Suffolk City	0.0%	0.0%	4.5%	63.0%	27.8%
Oceana Solar	17.6	Virginia Beach City	0.0%	0.0%	0.0%	93.4%	0.0%
Palmer Solar	5	Fluvanna	0.0%	0.0%	0.0%	79.3%	0.0%
Pamplin Solar	15.7	Appomattox	0.0%	0.0%	0.0%	0.4%	0.0%
Puller Solar	15	Middlesex	0.0%	0.0%	0.0%	0.6%	75.3%
Remington Solar	20	Fauquier	0.0%	0.4%	19.7%	52.4%	24.8%
Rives Road Solar	19.7	Prince George	0.0%	0.0%	0.0%	5.4%	51.6%
Sadler Solar	100	Greensville	0.0%	0.0%	0.0%	0.0%	0.3%
Sappony Solar	20	Sussex	0.0%	0.0%	0.0%	5.6%	84.3%
Scott Solar	17	Powhatan	0.0%	0.0%	0.0%	0.0%	0.0%
Scott-II Solar	20	Powhatan	0.0%	0.0%	0.0%	0.0%	0.9%
Southampton Solar	100	Southampton	0.0%	0.0%	12.8%	10.0%	69.8%
Spotsylvania Solar	300	Spotsylvania	0.0%	0.0%	0.3%	1.6%	1.9%
Spring Grove I Solar	97.9	Surry	0.0%	0.0%	0.1%	0.2%	1.4%
Twittys Creek Solar	13.8	Charlotte	0.0%	0.0%	0.0%	0.0%	0.0%
UVA Hollyfield Solar	17	King William	0.0%	0.1%	11.2%	2.1%	86.6%
Whitehouse Solar	20	Louisa	0.0%	0.0%	0.1%	12.0%	0.0%
Woodland Solar	19	Isle of Wight	0.0%	4.2%	22.5%	49.6%	21.6%

Table B6. *Demographic Information for Census Tracts with Solar Facilities (Census Tract; ACS 2019)*

Name	MW	County	Total Population	Population Density (Per Sq. Mile)	% White Population	% Black Population	% Other Race Population	Median Household Income (2019)	Poverty Rate	Median House Value
Martin Solar	5	Goochland	4369	42.6	73.2%	22.4%	4.4%	69743	5.40%	$208,200
Palmer Solar	5	Fluvanna	6181	143.0	77.4%	18.6%	4.0%	76571	5.10%	$278,800
Kentuck Solar	6	Pittsylvania	3952	188.0	66.4%	32.2%	1.4%	44467	23.50%	$141,300
Irish Road/Whitmell Solar	10	Pittsylvania	2755	50.5	87.2%	6.1%	6.7%	54699	9.90%	$147,500
Clarke Solar	10	Clarke	3048	48.8	89.7%	6.1%	4.2%	87417	4.10%	$346,300
Danville Solar	12	Pittsylvania	6276	64.7	86.6%	8.7%	4.7%	47346	20.00%	$95,300
Twittys Creek	14	Charlotte	5392	29.9	77.1%	19.7%	3.2%	35387	32.40%	$139,700
Gardys Mill	14	Westmoreland	4561	49.7	53.7%	45.1%	1.2%	53448	16.20%	$184,100
Puller Solar	15	Middlesex	2560	110.2	87.0%	13.0%	0.0%	46719	11.60%	$252,800
Myrtle Solar	15	Suffolk City	2144	69.7	89.7%	4.0%	6.3%	84632	1.90%	$315,000
Pamplin Solar	16	Appomattox	4341	29.6	78.6%	18.9%	2.5%	57105	14.40%	$142,900
Hollyfield Solar	17	King William	4423	48.0	71.9%	24.8%	3.3%	62371	15.70%	$206,600
Scott Solar I	17	Powhatan	8933	137.0	93.8%	3.5%	2.6%	86469	5.60%	$291,200
Oceana Solar	18	Virginia Beach City	2574	311.1	71.6%	18.5%	9.9%	n/a	n/a	n/a
Briel Solar	19	Henrico	5954	635.1	41.7%	55.5%	2.9%	48859	15.60%	$162,800
Woodland Solar	19	Isle of Wight	3845	40.2	70.4%	26.8%	2.8%	87739	4.00%	$246,400
Whitehouse Solar	20	Louisa	5576	96.3	66.3%	24.5%	9.2%	44531	18.80%	$189,700
Sappony Solar	20	Sussex	2454	14.9	38.7%	54.4%	6.9%	46250	18.60%	$95,600
Buckingham Solar	20	Buckingham	5740	59.8	57.0%	38.9%	4.1%	48750	18.10%	$144,900
Cherrydale Solar	20	Northampton	3442	48.1	62.4%	33.7%	4.0%	58750	15.70%	$218,200
Montross Solar	20	Westmoreland	3430	57.4	65.7%	29.2%	5.1%	60349	12.10%	$174,700
Essex Solar	20	Essex	3665	50.5	64.6%	24.5%	10.8%	67661	12.60%	$216,300
Gloucester Solar	20	Gloucester	3825	161.0	83.1%	14.2%	2.7%	68542	11.80%	$274,500
Rives Road	20	Prince George	5311	199.3	59.4%	33.9%	6.8%	75012	4.60%	$182,100
Remington Solar	20	Fauquier	5822	362.0	81.1%	10.7%	8.2%	85141	9.60%	$265,600
Scott Solar II	20	Powhatan	8933	137.0	93.8%	3.5%	2.6%	86469	5.60%	$291,200
Correctional Solar	20	New Kent	9758	85.8	80.1%	11.8%	8.1%	93352	10.80%	$311,700
Hickory Solar	20	Chesapeake City	9654	166.6	67.5%	27.9%	4.6%	100461	5.50%	$390,000
Mechanicsville Solar	20	Hanover	3062	101.0	87.4%	5.3%	7.3%	103362	1.10%	$341,200
Bluestone Solar	50	Mecklenburg	4838	45.7	53.3%	42.1%	4.6%	34958	24.80%	$101,300
Grasshopper Solar	80	Mecklenburg	4838	45.7	53.3%	42.1%	4.6%	34958	24.80%	$101,300
Eastern Shore Solar	80	Accomack	5771	79.6	68.8%	28.5%	2.7%	40779	10.50%	$154,800
Greensville Solar	80	Greensville	4124	22.8	37.9%	61.1%	1.0%	50840	12.50%	$87,700
Spring Grove I Solar	98	Surry	2933	33.0	51.0%	45.0%	4.0%	49193	25.30%	$231,200
Sadler Solar	100	Greensville	4124	22.8	37.9%	61.1%	1.0%	50840	12.50%	$87,700
Southampton Solar	100	Southampton	3706	23.3	60.3%	36.8%	2.9%	60250	9.10%	$160,800
Colonial Trail West	142	Surry	2933	33.0	51.0%	45.0%	4.0%	49193	25.30%	$231,200
Pleinmont Solar	300	Spotsylvania	5405	111.4	81.5%	11.1%	7.3%	119643	4.50%	$434,300