UTILITY-SCALE SOLAR CONSTRUCTION: BEST PRACTICES FOR REDUCING COSTS AND ENSURING ENVIRONMENTAL COMPLIANCE

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Executive Summary

The environmental benefits of solar power are well known as an energy source that emits minimal greenhouse gases during operation, but there are environmental risks to address during and after construction that cannot be ignored. Unfortunately, environmental stewardship can come with high costs. Using additional measures to minimize environmental impact can slow a project down, add unwanted costs, and prevent the owner from making full use of the land.

The utility-scale solar industry has grown rapidly over the last decade and is set up to build on millions of acres of land across the globe in years to come. The electricity generated by these large plants will help mitigate the damaging effects of climate change by supplanting fossil fuels as an energy source, but the interaction between the solar farms and their local environment warrants further investigation. Future research will be required to quantify the local environmental impacts of solar farms, but these impacts have been observed and accounted for by professionals working in the industry over the last decade. I have personally been involved in the design and construction of several utility-scale solar projects totaling over 250 MW of capacity in the last three years. In that time, I've experienced the frustration of inconsistent guidance and regulatory hurdles regarding environmental management so I chose a capstone project that would help provide clarity and improve the efficiency of myself and the solar developers I work with.

Experiences and insights were collected from professionals familiar with the construction of utility-scale solar farms as part of this study. By comparing the information obtained in the interviews, a series of best practices were identified to streamline the environmental protection portion of solar farm construction while being flexible enough to be applied across states with markedly different regulatory approaches.

Table of Contents

Introduction

Solar photovoltaic (PV) electricity generation is growing worldwide with a global installed capacity of 480 GW in 2018, up from only 22.6 GW in 2010 (IRENA, 2019). In the United States, 37 GW of installed capacity comes from utility-scale solar farms with another 74 GW currently in development as of 2019 (SEIA, 2019). These projects primarily use ground-mounted crystalline silicon PV panels collectively spread across millions of acres of land. This paper focuses on utility-scale solar farms, ground mounted solar facilities with a capacity greater than 1 MW. The global environmental merits of solar power are well known as a renewable energy source that emits minimal greenhouse gases (GHGs) during operation. But the interaction of solar farms with the local environment is less understood. Potential impacts of solar infrastructure on biodiversity, land cover change, soils, and water quality all demand consideration as governments and industries push for more renewable energy to replace greenhouse gas (GHG) producing fossil fuels in the energy mix. This is especially true in the southeastern United States where the availability of sunlight has made solar an attractive option but also where powerful storms, dense population centers, and poor natural resource management can combine with distressing effects on the local population and ecosystems. As solar power becomes a more popular renewable energy source, more utility-scale solar farms will be built, and more land will be needed in order to develop them. It is important to consider actions necessary to prevent potential impacts that can come from large solar developments that occupy significant tracts of land. But before examining what mitigation strategies to employ, it is necessary to understand the causes of the impacts from the design of the solar panels themselves to the land modifications that must take place for their installation (Lee, 2019).

Focusing specifically on states in the southeast U.S., North Carolina and Florida are both among the top five states in the U.S. for total installed solar capacity with about 5600 MW and

3330 MW respectively (SEIA, 2019). South Carolina has the potential to grow as a market for utility-scale solar development with its tracts of favorable land available. Maryland ranks 14th nationally with over 1100 MW installed which is notable for the ninth smallest state in terms of land area. Virginia only has around 800 MW installed to date, but that number is set to rise following the completion of the 500 MW Spotsylvania Solar Energy Center currently in development. Florida, Georgia, Virginia, and North Carolina all rank among the top ten states in projected solar capacity growth over the next five years (SEIA, 2019). Environmental laws governing the construction phase of solar farms is just one of many policy determinations that affects the extent of solar capacity installed in each state.

To decarbonize the electricity supply and support climate change mitigation goals, governmental organizations have applied policy incentives for solar energy. More than half of U.S. states have implemented some type of Renewable Portfolio Standard (RPS) that requires utilities to procure a certain amount of the energy they sell from renewable sources like wind, solar, or hydropower (DSIRE, 2019). Policy incentives to support renewable energy focus on expanding the generation capacity of renewables through some means such as tax credits, taxing emissions, or establishing cap and trade regimes. All for the purpose of reducing greenhouse gas emissions and mitigating dangerous climate change and its associated effects (Allen et al. 2009). In the southeast, North Carolina is pursuing a goal of 12.5% of electricity from eligible renewable sources by 2021, Virginia has a voluntary goal of 15% of base year (2007) sales by 2025, Maryland has a goal of 25% of electricity from renewables by 2020, while South Carolina has a lesser goal of 2% of aggregate generation capacity by 2021 (DSIRE, 2019). These are only a few examples as 35 states so far have implemented some form of RPS.

Companies take advantage of these policy incentives to build new solar PV facilities that help meet the RPS goals. The added solar capacity delivers environmental benefits, the most important being the displacement of GHG producing fossil fuels. But there are environmental tradeoffs from land modification that occur during and after construction of utility-scale solar farms that must be accounted for in project timelines and costs. Environmental considerations are also a key component of the permitting process which can be a rate-limiting step for solar farm installation. As solar power seeks to become more cost competitive with traditional fossil fuels, it is important that soft costs are reduced and that delays in design and construction are avoided. However, using additional measures to minimize environmental impact can slow a project down, add unwanted costs, and prevent the developer from making full use of the land.

Little peer-reviewed literature exists to discuss environmental design and construction of solar facilities. Most studies concerning the environmental impact of solar farms focus on the manufacturing of solar panels, avoided greenhouse gas emissions, water usage, and material disposal (Turney and Fthenakis 2011). Some qualitative work has been published about the construction and operation of solar facilities, but the results lack clarity on how the information can be effectively used to facilitate the permitting process, which can bottleneck solar development due to local agencies addressing environmental concerns. Further research is needed to determine to what extent can utility-scale solar farms be designed and permitted to mitigate geohydrological impacts and ensure compliance with environmental regulations while minimizing the soft costs of engineering, labor, permitting, and inspection in the southeastern United States.

Background

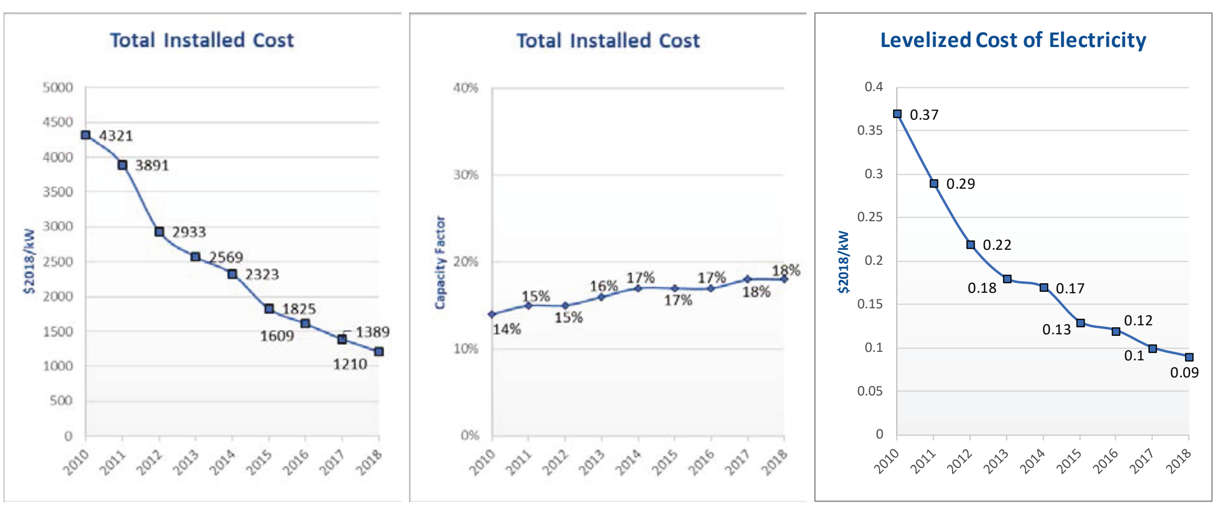
Soft costs are all the non-hardware costs associated with solar. This can include taxes, installation labor, fees, corporate overhead, permitting, and environmental compliance. According to 2017 data from the U.S. Energy Information Administration annual capacity-weighted construction costs for utility-scale solar PV systems in the United States has declined from \$3,700/ kW in 2013 to \$2,343 in 2017 (EIA, 2018). Soft costs must be reduced as much as possible to help solar improve its competitiveness in the electricity generation market. This paper will discuss in further detail how soft costs of permitting and environmental compliance can be reduced without inflicting undue environmental harm.

Prior to installation of a utility-scale PV farm, the solar development company must apply for and receive all necessary zoning, building, electrical, and environmental permits. These permit requirements differ across more than 18,000 jurisdictions nationwide and are subject to local codes and ordinances (Ulrich, 2016). Permit regulations are intended to ensure that public safety requirements and engineering standards are met. Though inconsistencies in with permit policy and enforcement among various authorities having jurisdiction can create barriers to solar expansion (USCA, 2018).

Once permits are in place, installation of such facilities begins with stripping of the land to remove trees, brush, and roots. The land is then graded as necessary to accommodate the slope limitations of the PV panels. Grading requirements change depending on the racking manufacturer or the type of panels, fixed tilt versus tracking, but typically require all slopes to be less than 10%. At the beginning of land clearing operations, the contractor performing the work must install erosion and sediment control measures that have been designed and permitted specifically for that project to treat stormwater runoff. The panels are then mounted onto metal posts that can be either driven into the ground or set on concrete footings. Larger electrical equipment like inverters and transformers typically sit on concrete pads. Cables are installed through some combination of hanging them below the panels or trenching them into the ground. Access roads must be built throughout the system for use during construction and system operation. Land clearing represents the most significant potential environmental impact and the means of doing so are subject to scrutiny during the permit review phase. This is also where developers and engineers have the most flexibility to balance cost against environmental protection by trying to preserve the natural function of native vegetation to the maximum extent practical.

Levelized cost of electricity (LCOE) from the U.S. Energy Information Administration estimates that solar PV has a total system LCOE of $60.0/MWh for new generation resources entering service in 2023. That number drops to $45.7/MWh with federal tax credits included. For comparison, conventional combined cycle natural gas has a total LCOE of $46.3/MWh. For solar to continue its expansion beyond the lifetime of the federal tax credits it must continue the dramatic decline in cost of electricity from utility-scale solar farms since 2010 to become more competitive with the costs of cheap fossil fuels (IRENA, 2019). These cost reductions can come by way of PV technology improvements and reduction in soft costs that can account for up to 64% of the total installation and operation cost (Ulrich, 2016). Figure 1 below shows how solar PV installation costs have fallen, how capacity factors of solar panels have increased from technology improvements, and how the LCOE has fallen since 2010.

Figure 1: Global total installed costs, capacity factors and LCOE for solar PV, 2010–2018



Source: International Renewable Energy Agency, Renewable Power Generation Costs in 2018 (IRENA, 2019)

The capacity factor shown in Figure 1 is a ratio of the energy generated divided by installed capacity. Reducing the soft costs of environmental compliance of utility scale solar farms is one step towards continued improvement on installation costs and LCOE to ensure its progress in meeting global clean energy goals. This study takes a qualitative approach to studying environmental risks associated with solar farms and cost-effective mitigation strategies.

Methods

There remains a lack of quantitative research addressing the interaction between utility-scale solar energy and the local environment. With tens of thousands of acres of U.S. land proposed for future solar development, the environmental impacts associated with construction and operation warrant further research and understanding (Turney and Fthenakis, 2011). This study aims to collect opinions and experiences from a variety of professionals with relevant experience related to utility-scale solar construction and use it to help bridge the empirical gap in a way that aids solar developers and policymakers to expand the share of solar in the electricity mix. The focus here is on southern states along the east coast of the U.S. States that have similar geophysical regions and available solar insolation for harvesting but vary markedly in terms of overall solar capacity installation due to policy differences. One of which is the environmental review process that solar projects are subject to.

Study Participants

Interviews were conducted with a range of professionals including environmental review authorities and employees of private solar development companies. The environmental authorities interviewed include two professional engineers, one with the Virginia Department of Environmental Quality (DEQ) Water Permitting Division and one municipal stormwater plan reviewer in North Carolina. On the private sector side, interviews were completed with owner of a Maryland-based company that specialized in solar project development in the east coast and the Midwest and the vice president of a North Carolina-based solar engineering, procurement, and construction firm. The identities of the interviewees have been kept anonymous for this study.

Data Collection and Analysis

Semi-structured interviews were conducted following a list of topics and open-ended questions related to the environmental impacts of solar projects. The depth of the interviews allowed participants to add personal insight and anecdotes and to expand upon the initial script of topics. All interviews were recorded and transcribed with informed consent given by the participants. For research design and analysis, a loose topic guide was used to ensure a comparable range of topics were discussed with each participant to be able to analyze similarities and differences. But some of the specific questions asked were tailored to the participants' area of expertise. Some of the questions discussed in all interviews include:

- Have you observed any erosion, stormwater, or groundwater impacts in solar projects you've been involved in?
- Do you believe permanent stormwater treatment facilities are necessary?
- Have you seen any specific design strategies that have helped to expedite the permit process?
- From an environmental regulation perspective, are solar farms treated differently than other types of commercial or residential development?
- What long-term environmental maintenance problems to solar farms typically have? Do you believe these could be affected by proper design and planning up front?

Solar developers were also specifically asked about the percentage of construction costs that go into erosion control measures on their construction sites, local opposition to their projects, long term operation and maintenance problems, and permitting delays.

The transcripts were coded and indexed based on over-arching themes that emerged from the interview. A descriptive coding process was used to map words and phrases that summarize the primary topic of transcript excerpts. A second iteration of code mapping organized the codes into categories while the third iteration solidified categories into three to five broader themes. With the small number of interviews conducted, unique themes emerged from each interview that reflected the knowledge and beliefs of individual participants. To ensure validity of the analysis, the same method of descriptive coding was applied to all transcripts and statements referring to laws and policies were verified through supporting background research following completion of the qualitative analysis. Topics raised across all interviews included environmental tradeoffs between clean energy and land disturbance, stormwater quantity and quality concerns, environmental regulation, solar farm permitting, and long-term environmental maintenance problems of solar farms. The intent was to open the conversation and allow the developers to go into detail on issues and outcomes of specific projects.

Results

Two to four themes emerged from each interview following the analysis of the codes and categories from each transcript. The participants all had unique backgrounds that relate to the solar industry in different ways so different sets of themes emerged from each interview. The themes are categorized as common themes and individual themes. Common themes come from two or more participants while individual themes were found in only one participant interview.

Common Theme 1: Environmental Concerns

The two study participants that work with state and local governments expressed concerns about the long-term impacts of solar farms on the local environment. The top concerns for each of them were the effects of solar panels on stormwater runoff. Utility-scale solar farms have a large land footprint, sometimes several hundred or even several thousand acres depending on the project. Undisturbed, vegetated land is best for absorbing stormwater and limiting runoff that can contribute to flooding downstream. Rain falling on the panels will immediately flow off and reach the ground, but the study participants pointed out that the water will tend to concentrate along the dripline of the panels and create small erosive ditches. This leads to problems with soil erosion and weakens the ability of the undisturbed ground beneath the panels to absorb stormwater, therefore increasing total runoff which environmental review authorities are always looking to avoid.

The environmental regulators that participated also described how they regulate solar projects and the laws that enable and constrain their ability to enforce standards. The municipal official in North Carolina expressed his displeasure at a state law that prevents them from acknowledging increased stormwater runoff from the solar panels during the permit review process while the Virginia DEQ employee described common violations they see and how they enforce their standards. As he explained,

> "We can take that approved erosion and sediment control plan. It's an enforceable part of the permit, and we can pretty much hold people's feet to the fire. And when they don't follow it, that's when we usually notice that there are problems."

Common Theme 2: Permit Review and Regulation

The permitting process for building utility-scale solar farms was brought up in each interview, and it ultimately emerged as a significant theme in three out of the four interviews. Solar farms require multiple permits prior to construction including but not limited to building, electrical, encroachment, construction, and zoning permits. Though the exact number and type of permits needed varies by locality. In the context of environmental compliance, the general construction permits are typically where environmental concerns are addressed. The federal Environmental Protection Agency regulates any construction project larger than one acre, though it delegates authority for permit reviews down to states and municipalities as explained by one participant. As one of the solar developer participants described, public opposition to solar projects due to environmental concerns can sometimes be brought up during zoning and conditional use permit reviews.

Also discussed were the design calculations used to quantify environmental impacts to the land. Hydrologic modelling and runoff reduction calculations are typically part of the design and review process prior to construction. Solar developers and permit reviewers had conflicting opinions on how the calculations ought to be performed. Solar company employees arguing that solar projects have minimal impact on the local environment once completed while environmental quality specialists are skeptical of that conclusion and prefer to impose a more conservative design approach. Without any real quantitative research available to support one side or the other, it comes down to the opinion of the permit reviewers and their authority to interpret and enforce their laws.

Common Theme 3: Solar Project Development

Utility-scale solar project phases, construction, and associated costs fell under the theme of Solar Project Development. Solar project development goes through land acquisition, application for interconnection, due diligence investigations (wetland delineation, geotechnical investigations, zoning requirements, etc.) design and permitting, and construction, and operation and maintenance. All participants interviewed referenced portions of this process. Participants that worked in the solar industry stressed the need to minimize costs within the early phases of a project to keep it financially viable. One participant with a solar company based in Maryland spoke of having to walk away from potential projects because the development and review costs were assumed to be too high. The study participants working in environmental regulation were aware of their role in the overall process but were mostly concerned with the long-term environmental compliance of the projects rather than potential short-term cost savings.

Common Theme 4: Environmental Policy

The Virginia DEQ official interviewed spoke of the state laws and policies in place that allow them to place stringent environmental compliance measures on solar farms. When accounting for stormwater runoff, Virginia identifies three categories of land classification based on the land's ability to absorb stormwater and preventing runoff. To them, land clearing and installation of solar panels degrades the land below the ideal functionality of a natural forest or open space, so they require developers to build some type of stormwater detention facilities to control runoff and make up for the degradation that the project causes. The municipal official from North Carolina indicated that he is required to treat solar panels as if they have no impact on stormwater runoff which he believed was a political decision, not a scientific one. In his words, "They had to have a ruling of some sort and it was politically decided to encourage solar farms rather than the discourage them. And so that's the ruling that came down."

Individual Theme 1: Technical Considerations

A discussion about engineering design options for improving the environmental performance of solar farms revealed a series of technical constraints that developers are bound to. Developers must submit interconnection applications to the electric utility that they intend to deliver power to 3-4 years before the project can begin, knowing that's how long the interconnection review could take. Part of the interconnection application must state the intended AC power capacity that the project will support.

Years later when they must build enough solar panels to reach the agreed upon capacity, they may find themselves having to utilize undesirable portions of their sites such as wetlands or low-lying areas simply because they have no other choice. the North Carolina-based developer explained why it is so important to build to the agreed upon AC capacity, "The AC number be reduced by as much as 10% of the total. And if it has to go lower than that, then you've got to basically reapply [for interconnection]. And after you've been in the queue for three or four years, you don't do that."

Construction can be sequenced to minimize permitting requirements, but all sites come with certain limitations that be expensive to overcome.

Individual Theme 2: Public Perception

The Maryland based solar developer described his experiences combating public opposition to solar projects in their communities. Public resistance to solar development is not necessarily rooted in disapproval of solar energy. Some people oppose any type of development in their community and will grasp at any reason to justify preventing it. Environmental considerations like tree clearing and stormwater runoff are some of the reasons raised in opposition even if actions are taken by the developer to mitigate their effects. He described the public resistance on one of his projects where the permit was denied.

> "It's not because it's solar. It's because it's development. The people just didn't want anything. It wasn't really solar-specific. So they just come up with everything they can come up with to oppose it."

Discussion

Any solar farm with a capacity greater than 1 MW is considered utility-scale as opposed to smaller commercial or residential solar generation facilities. Utility-scale solar farm development typically requires 2.5 – 5 acres of land per MW of capacity. Land modifications associated with solar farm development can vary depending the initial condition of the land. To build solar farms in the southeastern United States forested tracts must be cleared to make way for panel installations and to prevent shading, steep terrain must be graded to accommodate the slope limitation of the solar racking systems and flat terrain requires drainage improvements to make the site constructible and prevent ponding. The known environmental concerns associated with land disturbance include soil erosion, vegetation removal, increased quantity of stormwater runoff, reduction in stormwater quality, and reduction in groundwater recharge (Hernandez et al., 2014). A common theme that emerged from conversations with permit reviewers in Virginia and North Carolina and with the Vice President of a North Carolina-based solar development company about these issues was the environmental concerns.

Permit review and regulation was an important theme that was addressed in all interviews. Applying for and obtaining permits for land modifications is a critical step in any utility-scale solar project as all participants in this study confirmed. Construction projects that disturb one or more acres of land are required to apply for permit coverage under the Construction General Permit, part of the National Pollutant Discharge Elimination System (NPDES). The NPDES permit program was created in 1972 by the Clean Water Act. Under this program the federal EPA authorizes state governments to perform permitting, administrative, and enforcement aspects of the program (EPA, 2019). Stormwater is considered a pollutant associated with construction activity because it can carry nutrients and sediment away from the site and cause water quality problems downstream. Stormwater runoff is known to increase total nitrogen and total phosphorus in receiving waters which lead to increased growth of algae and aquatic plants which result in eutrophication, or decreased levels of dissolved oxygen in the water.

The participant in this study employed by Virginia DEQ referenced the organization's authority to review projects and issue permits under the state level pollutant discharge elimination system. However, Virginia goes a step further by requiring permit applicants to develop and implement a post-construction stormwater management plan to mitigate downstream impacts associated with increased storm water runoff volume and the change in runoff quality. Change in runoff quality could mean the addition of nutrients like nitrogen or phosphorus or pollutants like heavy metal or hydrocarbons. Developers are also required to mitigate the volume of runoff by calculating the pre- and post-construction stormwater runoff volumes and ensuring that the peak stormwater discharge following a storm event is lower than it was prior to the construction activity. Most construction activities increase the imperviousness of the land surface and contribute to greater stormwater runoff volumes, so Virginia requires large construction projects to build permanent stormwater best management practices (BMPs) to capture and treat stormwater on-site, then release it at a slower rate. BMPs are structural, vegetative, or managerial practices used to reduce pollution. Structural BMPs can involve some type of detention pond or swale. The state of Virginia has a BMP clearinghouse with 17 approved BMPs for use in construction projects (Virginia Department of Environmental Quality, n.d.). The BMPs associated with any post-construction stormwater management plan must be in place before the permit can be closed out. Figure 2 demonstrates three BMP examples from the Virginia BMP clearinghouse.

Figure 2: Stormwater Best Management Practices

Extended Detention Pond

An Extended Detention (ED) Pond relies on 12 to 24 hour detention of stormwater runoff after each rain event. An under-sized outlet structure restricts stormwater flow so it backs up and is stored within the basin. The temporary ponding enables particulate pollutants to settle out and reduces the maximum peak discharge to the downstream channel, thereby reducing the effective shear stress on banks of the

Wet Swale

Wet swales can provide runoff filtering and treatment within the conveyance system and are a cross between a wetland and a swale. The saturated soil and wetland vegetation provide an ideal environment for gravitational settling, biological uptake, and microbial activity.

Filtering Practices

Grass channels can provide a modest amount of runoff filtering and volume attenuation within the stormwater conveyance system resulting in the delivery of less runoff and pollutants than a traditional system of curb and gutter, The performance of grass channels will vary depending on the underlying soil permeability

Virginia DEQ publishes the Virginia Runoff Reduction Method (VRRM) spreadsheet for engineers to use when performing stormwater calculations as part of the Construction General Permit application. The VRRM spreadsheet classifies land surfaces into one of three categories: Forested/Open Space, Managed Turf, and Impervious. Forested/Open space is undisturbed, protected space while manage turf is defined as disturbed, graded for yards or other turf to be mowed/managed. When evaluating solar projects, Virginia DEQ forces permit applicants to designate a change from forested/open space to managed turf which correlates to approximately a 4-25% increase in runoff volume per the VRRM spreadsheet depending on the soil type. Engineers must then design additional measures to capture that additional stormwater runoff in post-construction conditions to prevent a net increase.

<u>Figure 3: Runoff Volume Summary from the Virginia Runoff Reduction Method Spreadsheet</u>

Engineers classify drainage areas by size and land cover. Below is a table from the VRRM Excel spreadsheet published by Virginia DEQ that shows how land cover data is entered into the spreadsheet to perform the calculations. No data has been entered in the example below.

Drainage Area Curve Numbers and Runoff Depths*

Curve numbers (CN, CNadj) and runoff depths ($RV_{Developed}$) are computed with and without reduction practices.

Drainage Area A		A Soils	B Soils	C Soils	D Soils
Forest/Open Space -- undisturbed, protected forest/open space or reforested land	Area (acres)	0.00	0.00	0.00	0.00
	CN	30	55	70	77
Managed Turf -- disturbed, graded for yards or other turf to be mowed/managed	Area (acres)	0.00	0.00	0.00	0.00
	CN	39	61	74	80
Impervious Cover	Area (acres)	0.00	0.00	0.00	0.00
	CN	98	98	98	98

Total Area (acres):	0.00
Runoff Reduction Volume (ft^3):	0

$CN_{(D.A. A)}$
0

	1-year storm	2-year storm	10-year storm
$RV_{Developed}$ *(watershed-inch)* with no Runoff Reduction*	0.00	0.00	0.00
$RV_{Developed}$ *(watershed-inch)* with Runoff Reduction*	0.00	0.00	0.00
Adjusted CN*	0	0	0

<u>Runoff Coefficients:</u> The three land cover categories, Forest/Open Space, Managed Turf, and Impervious Cover each have a curve number (CN) assigned based on the soil type. Higher curve numbers indicate higher runoff potential. Soils are also classified into hydrologic soil groups based on the soil's runoff potential with A soils being well drained and D soils being poorly drained. Undisturbed, forested land with type A soils has the lowest overall runoff potential.

*Virginia DEQ BMP Clearinghouse 2011 Design Specifications Retrieved from https://www.swbmp.vwrrc.vt.edu/

The Virginia DEQ participant in this study made it clear that solar projects are treated no differently than any other large construction projects that fall under their jurisdiction. However, there have been conversations among the state of Virginia and solar companies operating there about potential changes to the way they are required to calculate the effects of their panels on stormwater runoff. Solar companies believe that the runoff coefficient for their arrays should be less than what it has been assigned under the "Managed Turf" classification, meaning that the real increase in stormwater runoff volume should be less than what the spreadsheet calculations show. Using a smaller curve number would reduce the need for BMP's, which can be expansive to construct and maintain and take up space that could otherwise be used to build solar panels.

As of October 2019, some solar companies in Virginia have recently approached DEQ about performing a scientific study to more accurately quantify the impacts of solar arrays on stormwater runoff. The only comparable study to date on the hydrologic response of solar farms was published by the American Society of Civil Engineers in 2013. The study concluded that if the grass underneath the panels is maintained, then the solar panels have a negligible overall effect on the total volume of runoff or the peak discharge rates. This study only used model calculations rather than actual field measurements from a real solar farm (Cook & McCuen, 2013). If solar companies wish to persuade Virginia DEQ to loosen their design standards, a pilot study would need to be designed to determine new runoff coefficients. Virginia DEQ is open to the idea of commissioning this study, but there would need to be additional discussion about the methods employed to make sure the results could be easily compared to past studies by the Natural Resource Conservation Service that were used to create the VRRM calculations. The plan reviewer interviewed here was skeptical that the solar companies would get the results they want. The participant also noted that solar companies' reluctance to abide by state rules has given the industry a bad reputation among environmental regulators in Virginia. The two solar developers interviewed indicated that they have intentionally avoided working in Virginia because of how difficult and expensive the environmental compliance process is in that state.

North Carolina has a much different approach to regulating solar farms which is part of the reason North Carolina ranks 2nd in the U.S. in installed solar capacity while Virginia ranks 18th (SEIA, 2019). The North Carolina Department of Environmental Quality allows solar panels associated with ground-mounted solar farms to be considered pervious (NCDEQ, 2018). This means that regulators must treat them as if they have no effect on runoff. With this rule in place, solar developers avoid the need to construct and maintain permanent stormwater treatment facilities. The North Carolina municipal official participating this this study acknowledged that the rule was put in place as a political decision meant to encourage solar development but had doubts about the rule’s validity based on personal experience permitting and inspecting solar farms. The participant described how instead of a rainfall being evenly distributed over are the entire site of grass if the panels weren't there, it hits the panels and flow concentrates on the drip line from the panels themselves. He believed that only through very careful contouring of the site would solar companies achieve what the state of North Carolina giving them credit for. Other Southeastern states like Maryland, South Carolina, and Florida treat solar panels as pervious area to prevent developers from having to account for additional runoff. The North Carolina-based solar developer participant indicated that very few of their project sites across the Carolinas and Florida have permanent stormwater detention facilities. In general, they have very little need to maintain any kind of erosion control or stormwater management measures once the projects are completed because solar panels have minimal impact on the environment.

Permit reviews can last for several weeks to several months and become a bottleneck in the project development process that can introduce additional costs. A project cannot begin until the appropriate permits are in place. Delays in permitting can affect anticipated schedules for contractor mobilization and materials and equipment delivery to the project site. Having to reschedule deliveries and accelerate the construction schedule to meet the target completion date can cause developers to incur unwanted costs. One of the developer participants explained that they have experienced excess costs due to permitting delays every year that he had been with the company. He also explained how delays and associated costs can compound if they are late starting up a project. Weather delays can push back the start of earthwork and erosion control construction which is the first step in the building process. If construction is pushed too far, it might be more difficult to get a burn permit to dispose of the brush and debris that was cleared from the site, or the entrance driveway might not be built in time for concrete or equipment delivery trucks to access the site. To avoid these delays and the various costs associated with them, solar developers look to get land disturbance and environmental permits in place as fast as possible to provide them with flexibility in scheduling other elements of the project. Building and electrical permits are typically required as well, but those don't need to be in place for the initial work to begin.

Some permit reviews are performed by elected officials rather than technical experts, like zoning or conditional use permits depending on the requirements of the locality. These permits determine whether the land can be used to build a solar farm. These types of reviews are subject more to personal opinion rather than technical criteria as the Maryland-based developer described. He explained how one project of his in North Carolina was outright denied because local landowners voiced their displeasure with the planned solar project to the local board during a planning meeting. And because the board members are elected officials, they sided with their constituents regardless of the validity of their complaints. He also cited another permit denial for a project of his in Maryland that ended up going through a 17-month appeal process before finally getting approved. When asked about the particular reasons for public opposition, the participant believed that the people opposing his projects simply didn't want any new development in their communities whether that was solar or anything else. And to justify their opposition they point to issues like environmental damage or property value impacts. Some property value studies show that solar has no impact on adjacent property value if it is properly screened from view with a landscape buffer, but there is no clear consensus in the literature on the effect of solar farms on property value, positive or negative (Al-Hamoodah et al., 2018). The participant also explained that from his point of view, the public's environmental concerns consisted mostly of information gleaned from the internet that could easily be addressed or dismissed.

The Virginia DEQ participant referenced an ongoing project in Spotsylvania County, Virginia called the Spotsylvania Solar Energy Center. The project, approved in April 2019, is being developed by Utah-based company Sustainable Power Group (sPower). When completed, it will have a capacity of 500 MW and encompass approximately 6,350 acres of land making it the largest solar farm in the United States east of the Rocky Mountains. The project was approved after extensive review and deliberation by both county and state officials. During the review process the local community members raised concerns about the environmental impacts of the project. A report by the University of Richmond, which has partnered with sPower to purchase 20 MW of electricity from the project, analyzed the environmental concerns raised by the community and mitigation strategies employed by sPower. Below are some of the main environmental concerns of the local community and sPower's responses to those concerns.

Figure 4: Community concerns and sPower responses for the Spotsylvania Solar Energy Center

Concern/Claim	sPower's Response
Thousands of acres are to be cleared if the project is approved.	All current timber management and harvesting practices are being conducted by the current property owner.
Toxic runoff and contamination of our water supply	**Cadmium Telluride is not the same thing as free Cadmium.** Cadmium Telluride (CdTe) is an extremely stable, nontoxic compound. sPower has provided thorough evidence and research to County Staff demonstrating the chemical stability of CdTe. This research has demonstrated Cadmium Telluride is non-toxic, and passes EPA standards for environmental and human health and safety.
sPower needs more than 200 million gallons of water during 18 months of construction. In any event, sPower plans to withdraw the water they need from new large wells. The state will not impose restrictions on water usage. Any restrictions must be imposed by the county via the Special Use Permit conditions.	sPower has redesigned the grading and developments plans for the project that were initially proposed, which consequently reduced the anticipated water need to less than 100,000 gallons per day. It is worth noting this new grading plan comes at a considerable economic cost. sPower has made the commitment to utilize only municipal water, and will consider groundwater only during the emergency scenario of a municipal water system failure.
Most of the 6,350 forested acres have been logged and will be cleared. Significant soil regrading is anticipated to provide vast flat fields for the solar panels.	sPower has made significant and costly modifications to our grading plan, reducing the amount of grading and earthwork than what was previously proposed. Also, the project will be phased with only 400 acres open and active at any one time in any one watershed.
Specific plans are needed to prevent severe muddy runoff problems, such as recently encountered in Essex County due to construction of a 200 acre solar farm -- after only 1/2" of rain	sPower has committed to several Stormwater and Erosion control measure that go above and beyond what is required by county and state regulations, including but not limited to: sediment basins that are over-sized for their respective drainage areas, an accelerated sediment removal regime (cleaning the basins twice as frequently as required), diversion ditches on top of proposed slope to further divert and slow runoff, and stormwater conveyance channels and ditches at full design (a level of design effort reserved for the site development plan stage). Spotsylvania County has reviewed and approved these designs.
The soil in our area is not hydric, so rainwater will not percolate into the soil, but instead will rapidly runoff the Virginia clay which will be exposed by regrading the site.	See the above mentioned additional/excessive runoff control measures.
The reason that sPower must buy 6350 acres to install 3500 acres of solar panels is because the rest of the site is either wetlands, or is too steep to install panels. This site has a lot of streams and wetlands. It is not the typical topography for a solar power plant of this size. The environmental risks here are much greater.	All streams and wetlands have 100' designated Resource Protection Area (RPA) buffers surrounding them, as well as the above mentioned additional/excessive runoff control measures. Besides coordinating with County staff, sPower has coordinated and consulted with all relevant State and Federal agencies and will follow all applicable permits and regulations to ensure natural resource protections.

Sustainable Power Group. (2019). Concerns and Responses. Retrieved from https://spotsylvania-solar.spower.com/responses/

Most of the environmental concerns relate to muddy stormwater runoff increases and aquifer drawdown from excessive groundwater pumping for water use during construction and for washing panels. sPower addressed these concerns by modifying its grading plan to minimize water use, agreeing to use municipal water, and going above and beyond the state and local requirements for erosion control measures. All these changes impose additional engineering and construction costs on the developer. Additional concerns about property values, electricity prices, and decommissioning bonds are not listed here but were also addressed. As solar grows its share of the electricity mix, more large solar farms will need to be built and large tracts of land will be needed to develop them. A more efficient way to navigate the steps of project development and environmental compliance, especially in emerging markets like Virginia, Georgia, or South Carolina, without introducing additional costs is crucial to improving the competitiveness of solar.

The steps of solar project development theme appeared in interviews with all participants as several of these steps relate to the overall environmental impact of solar farms. The first step is acquiring land to build on. The two solar developer participants in this study indicated that the best to begin the lease several months before construction is scheduled to start. This gives either the solar developer or the landowner the opportunity to cut trees as necessary clear all the stumps and brush and stabilize the ground by planting grass. Doing this in advance of and grading or building work lessens the environmental impact later in the project and reduces the need to build stormwater detention facilities to control muddy runoff during construction. Having grass in place improves the ability of the soil to soak up rainwater and acts as a natural filter to clean the stormwater runoff. One of the participants cited a project in South Carolina where planting grass and stabilizing the ground prior to beginning construction of the solar facilities reduced the number of stormwater basins required by the permitting agency from 13 down to two and saved them $350,000 by his approximation.

Following land acquisition, engineering design can begin on the project to determine a cost-effective way to build to the required capacity as referenced under the technical considerations theme. Most utility-scale solar farms connect directly to a high voltage transmission line. As part of the interconnection agreement with the utility that will receive power from the solar farm, projects are required to build to a certain AC power capacity determined years before the start of construction. Solar panels generate DC power which must be converted to AC using inverters. Panels and electrical configurations are designed to meet the minimum required capacity. From an environmental perspective, having to build enough panels to meet the minimum capacity could force the developers to build on less favorable parts of a site like steeper slopes or poorer soils that require more expensive modifications and have a greater risk of environmental impact. Failing to meet the minimum AC requirement forces solar developers to reapply for interconnection, which can take three to four years which simply isn't an option from their point of view according to one participant.

While the design is in the works, permit applications can be submitted for review. At this point, solar developers are at the mercy of permitting agencies, as one participant described it. The only way to speed this process up is to apply for expedited permits where available which comes with additional cost. In Virginia, solar developers lobbied successfully for legislation allowing for expedited permit review. In 2018 Virginia House Bill 30 Item 368 allows for the voluntary option of requesting an expedited storm water review for a $30,000 fee that reduces review time from 180 days to 45 days (Virginia state budget, 2018). The North Carolina Department of Environmental Quality accepts expedited applications for a 2,000 review fee, while the South Carolina Department of Health and Environmental Control charges $10,000 for any project over 50 acres, though acceptance into the expedited review program depends on the availability of the staff to perform the review (SC DHEC, 2019).

Once permits are in place the project can begin construction. The construction phase is where the greatest threat of environmental impact exists. Impacts can be mitigated by building to the approved design standards and abiding by all permit conditions. When construction is complete, the site can be energized and move into the operation and maintenance (O&M) phase. At this point the level of environmental management required depends on whether any permanent stormwater BMPs were built at the site. If so, they must be regularly inspected, cleaned, and maintained to ensure they are functioning as designed. Developers prefer not to spend more time or money than necessary on O&M so permanent BMPs are avoided when possible. According to one participant, the greatest O&M cost is mowing the grass to keep up appearances and to prevent any tall weeds from growing high enough to reach the motors and tracking equipment underneath single-axis tracker panels because they have the potential to shade or seize up the system and damage energy output. According to one developer participant, as long as care is taken to permanently stabilize the site with healthy vegetative cover, costs for managing erosion after construction is completed are minimal.

Conclusion

Further research is needed to expand our understanding of the geohydrological impacts of utility-scale solar farms and what methods can be employed in the design and construction phases to mitigate those impacts and ensure compliance with environmental regulations while keeping project soft costs down. To develop environmentally compliant solar farms in the southeastern United States, developers should start by researching and understanding the local laws and ordinances governing environmental design and consider how they might affect the design overall project costs. It is more cost-effective to build in states that don't require developers to account for stormwater runoff quantity increases from solar panels to save on post-construction BMP costs. Developers should also seek to utilize agricultural land where possible to avoid altering land in its natural vegetative state like forests or grass field. Converting unplanted farmland to a solar farm with healthy vegetation under the panels is an overall improvement to the local environment that may quell public concerns and avoid risk of further environmental degradation.

Applying and paying for express permit reviews in the early stages of a solar farm project is beneficial and worth the cost if it can help avoid delays. If public hearings are part of the permit process, developers should clearly articulate the risks and mitigation strategies employed to help sway public opinion and prevent local opposition from shutting a project down. During construction, developers and contractors must follow well-established guidelines for erosion control measures, same as any other large construction project. But the need for erosion control practices can be dramatically reduced by seeding the site and growing grass in advance of any construction and by phasing construction to only work in smaller areas of the project at a time so that a smaller area of land is disturbed at any one time. Post-construction BMPs like permanent stormwater detention ponds should be avoided where possible to minimize O&M costs.

Further research and testing are needed to address the cumulative environmental impacts of utility-scale solar farms. But for now, the experiences and observations of individuals involved in the growing industry over the last decade create an effective blueprint for reducing costs and ensuring environmental compliance.

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