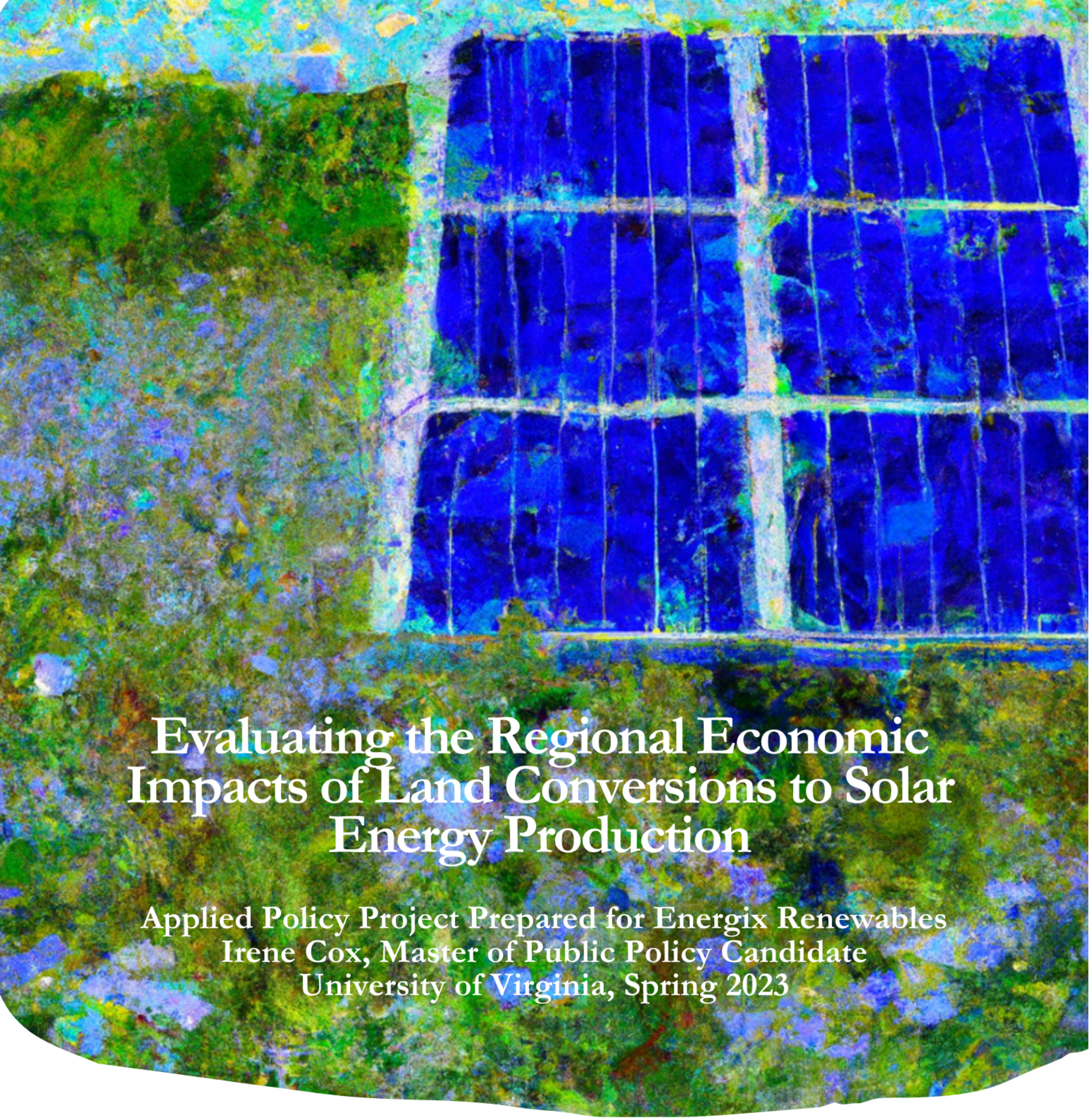

Evaluating the Regional Economic Impacts of Land Conversions to Solar Energy Production

Applied Policy Project Prepared for Energix Renewables
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University of Virginia, Spring 2023

UVA | FRANK BATTEN SCHOOL *of* LEADERSHIP *and* PUBLIC POLICY

ENERGIX RENEWABLES

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my professors and classmates at the Frank Batten School of Leadership and Public Policy. I especially thank Professor Andrew Pennock for his mentorship and invaluable feedback, both in this Capstone Project and in the practice of public policy. I also thank my Applied Policy Project group members, Charlie Groscup, Scott Rykala, and Madison McCaffrey—and my incredible roommate Casey Gottlieb. Your support, encouragement, and friendship are truly a gift.

I thank Kelsey Forren at Energix Renewables for bringing to my attention the policy challenges Virginia localities and solar developers face in responsibly evaluating the impacts of land-use change.

Over the past year, Elizabeth Marshall and Professor Bill Shobe at the Center for Economic and Policy Studies at the University of Virginia's Weldon Cooper Center for Public Service have provided me with excellent learning opportunities in researching the Commonwealth's renewable energy transition. I cannot thank them enough for their support and guidance in my professional development and academic endeavors.

Finally, to my parents, Bill and Marta Cox, and my dear sister Kara: Words cannot describe how grateful I am for, nor how humbled I am by, your unconditional love. Thank you for believing in and encouraging me.

DISCLAIMER

The author conducted this study as part of the program of professional education at the Frank Batten School of Leadership and Public Policy, University of Virginia. This paper is submitted in partial fulfillment of the course requirements for the Master of Public Policy degree. The judgments and conclusions are solely those of the author, and are not necessarily endorsed by the Batten School, by the University of Virginia, or by any other agency.

UNIVERSITY *of* VIRGINIA HONOR CODE

On my honor as a University of Virginia student, I have neither given nor received unauthorized aid on this assignment.

Irene Cox

Irene Cox
April 4, 2023

Cover Page Image Credit: *DALL-E Generative AI, Prompt from Irene Cox: "A pointillist-style painting in blue tones of a solar panel in a field surrounded by wildflowers."*

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Abbreviations

ApCo: Appalachian Power Company
BEA: U.S. Bureau of Economic Analysis
BLS: U.S. Bureau of Labor Statistics
CGE: Computable General Equilibrium
CPCN: Certificate of Public Convenience and Necessity
CSP: Concentrated Solar Power
DEQ: Virginia Department of Environmental Quality
EIA: Economic Impact Analysis *(Note: EIA is also a common acronym for "Environmental Impact Assessment." In this paper, EIA always refers to economic impact analysis, and environmental impact assessments are referred to without acronyms.)*
GAMS: General Algebraic Modeling System
GIS: Geographic Information Systems
HB 206: Virginia House Bill 206
IMPLAN: Impact Analysis for Planning
I/O: Input-Output
JEDI: Jobs and Economic Development Indicator
kV: Kilovolt
MCDA: Multi-Criteria Decision Analysis
MW: Megawatt
NOI: Notice of Intent
NREL: National Renewable Energy Laboratory
PBR: Permit By Rule
PPA: Power Purchase Agreement
REMI: Regional Economic Modeling, Inc.
RIMS: Regional Input-Output Modeling System
RPC: Regional Purchase Coefficient
SCC: State Corporation Commission
SEIA: Solar Energy Industries Association
USDA: United States Department of Agriculture
VACO: Virginia Association of Counties
VCEA: Virginia Clean Economy Act
VML: Virginia Municipal League

Executive Summary

Recent regulations make regional economic impact analyses (EIAs) more salient in evaluating the consequences of solar energy in Virginia, but the regulations themselves have tradeoffs and ramifications for developers and localities, who seek impartial guidance on how to measure the economic effects—direct and indirect—of utilizing the Commonwealth's land resources for solar electricity generation, particularly at utility-scale. This paper considers continuity and change in Virginia's energy regulation atmosphere related to House Bill 206, describes the causes and consequences of insufficient EIAs and implementation lags, and summarizes existing evidence both on land-use changes for photovoltaic production and on feasible EIA mechanisms.

Four policy options for improving the validity and usefulness of economic impact analyses conducted in the Commonwealth of Virginia on the regional impacts of converting land to solar generation are explored:

1. Let Present Trends Continue.
2. Standardize Procedures for Regional Input-Output (IO) Analysis.
3. Develop a Statewide Computable General Equilibrium (CGE) Model.
4. Refine the National Renewable Energy Laboratory (NREL) Jobs and Economic Development Indicator (JEDI) for Utility-Scale Solar Photovoltaic Projects.

The criteria by which these alternatives are evaluated include cost, empirical effectiveness, accessibility, administrative resilience, and implementation timeline.

This paper's final recommendation is to pursue **Alternative 4: Refine the National Renewable Energy Laboratory Jobs and Economic Development Indicator for Utility-Scale Solar Photovoltaic Projects.** Analysis suggests this Alternative would yield reasonably accurate impact assessments in a highly accessible format to the broadest population of stakeholders.

Problem Statement

Following Virginia's Spring 2022 Legislative Session, Governor Glenn Youngkin signed into law House Bill 206 (hereafter, HB 206), which directs state agencies to account for the environmental and natural resource impacts of converting fifty or more acres of contiguous forest or ten or more acres of USDA-designated prime agricultural land to solar generation, so solar developers can mitigate significant adverse impacts (Va. Stat. §10.1-1197.6, 2022). In accordance with HB 206 implementation, the Virginia Department of Environmental Quality (DEQ) convened a Solar Regulatory Advisory Panel to consider, among other factors, how "the impact on the local agricultural or forestry economy when [prime agricultural or forested] soils or lands are displaced [for solar generation]" shall determine "appropriate mitigation techniques or criteria" to be included in the mitigation plans solar developers submit to the DEQ or State Corporation Commission (SCC) when applying for state approval to proceed with a proposed site (DEQ 2022, p. 8; Va. Stat. §10.1-1197.6, 2022). The state government does not prescribe best practices for conducting economic impact analyses, which are not currently required in the site approval process for solar facilities but are presented to local governing bodies, and stakeholders express concerns that **economic impact evaluations of the effects of converting land to solar generation are inaccessible, and, where conducted, may be scoped inaccurately.**

Client Overview

Mission and Role

Energix Renewables is a reputable multinational solar developer with several successful utility-scale solar projects across the Commonwealth and a regional office in Arlington, Virginia. This client has requested a policy analysis of potential enforcement mechanisms for HB 206 directives, so that solar developers, specifically, as well as community stakeholders may run an *ex-ante* model analyzing the likely economic effects of converting prime agricultural or forested land from its primary use to solar generation. Alongside already-established environmental impact assessments, such data would allow the client to responsibly present the regional effects of land conversions in local proposals and enhance its capacity to mitigate any significant adverse impacts, in alignment with its organizational values of environmental stewardship and community partnership (Energix Renewables, *n.d.*).

Significance to the Client

An objective evaluation of which methods and contexts support solar developers' ability to conduct regional economic impacts analyses (EIAs) benefits multiple stakeholders. While HB 206 doesn't explicitly require localities to evaluate the regional economic effects of land conversions, it is in their interest and declared desire to do so (Marshall et al., 2022), and solar developers' proposals to local governing bodies will reflect any revised submission requirements to state agencies.

Virginia localities seek viable enforcement mechanisms for regional EIAs, which can affect the creation or restructuring of their solar ordinances and site approval processes. Identifying economic impact models and areas for improvement would help localities accurately measure the full economic effects of solar installations built in their area, enhancing their ability to adjust comprehensive plans, zoning ordinances, and evaluations of appropriate mitigatory techniques for land and economic disturbances.

Solar developers, for their part, seek updated local ordinances and site approval processes in compliance with HB 206 so they may assemble economically feasible proposals for solar installations. Suggesting a framework for localities' conduct of objective, suitably scoped regional EIAs could further protect developers from undue site rejections and prohibitively costly mitigation measures which could occur under the existing framework (Vogelsong, 2022): Where economic impact analyses are currently considered in local hearings for proposed solar projects, it is common for competing and even inappropriately calculated analyses to be presented by individuals who do not represent or hold a duty of objectivity to the local governing body (W. Shobe, personal communication, September 1, 2022).

Background

Solar Projects in the Commonwealth of Virginia: Growth and Governance

Between January 2016 and December 2022, sixty-two utility-scale (5 or more megawatts—MW—in capacity, as measured in alternating current) solar facilities began operating in Virginia, and as of February 2023, at least thirty-six proposed utility-scale solar facilities remain in regulatory approval or construction phases (EIA, 2023).[1]

FIGURE 1: Installation of Utility-Scale Solar Facilities in Virginia (Adapted from EIA, 2023)[2]

[1] Federal data do not include developers' submission of notices of intent (NOIs) to DEQ, and so may undercount the total number of projects proposed or being prepared for local proposal. Using NOIs to measure projects is not recommended, however, as the same facility may be proposed multiple times under different names and NOIs over time as owner-operators change or local approvals are repeatedly sought (Department of Environmental Quality, 2023).
[2] Data visualizations produced by author. Code available upon request.

Figure 1a (Top): *62 utility-scale solar facilities began operating in Virginia between Jan. 2016 and Dec. 2022, and 36 facilities are in local- or state-approval processes, under construction, or built but not yet in commercial operation as of February 2023.*
Figure 1b (Bottom Left): *Operating and Retired Energy Facilities in Virginia; A project age of 0 represents facilities that began operating in 2022.*
Figure 1c (Bottom Right): *Identical to Figure 1b, highlighting the relative recency of solar facilities.*

Solar facilities have proliferated rapidly in Virginia, as shown in **Figure 1:** Generation more than tripled between 2019 and 2021 (EIA, 2023), by which point Virginia was the fourth-leading state in the country for newly installed solar capacity and ninth in 2022 (SEIA, 2023). Utility-scale solar development will likely continue increasing as the Commonwealth's energy needs rise (PJM, 2022; Shobe, 2021), as Dominion Energy and Appalachian Power Company continue complying with the Renewable Portfolio Standard set under the Virginia Clean Economy Act, and as the costs of solar generation continue decreasing (Basore & Feldman, 2022, p. 2).

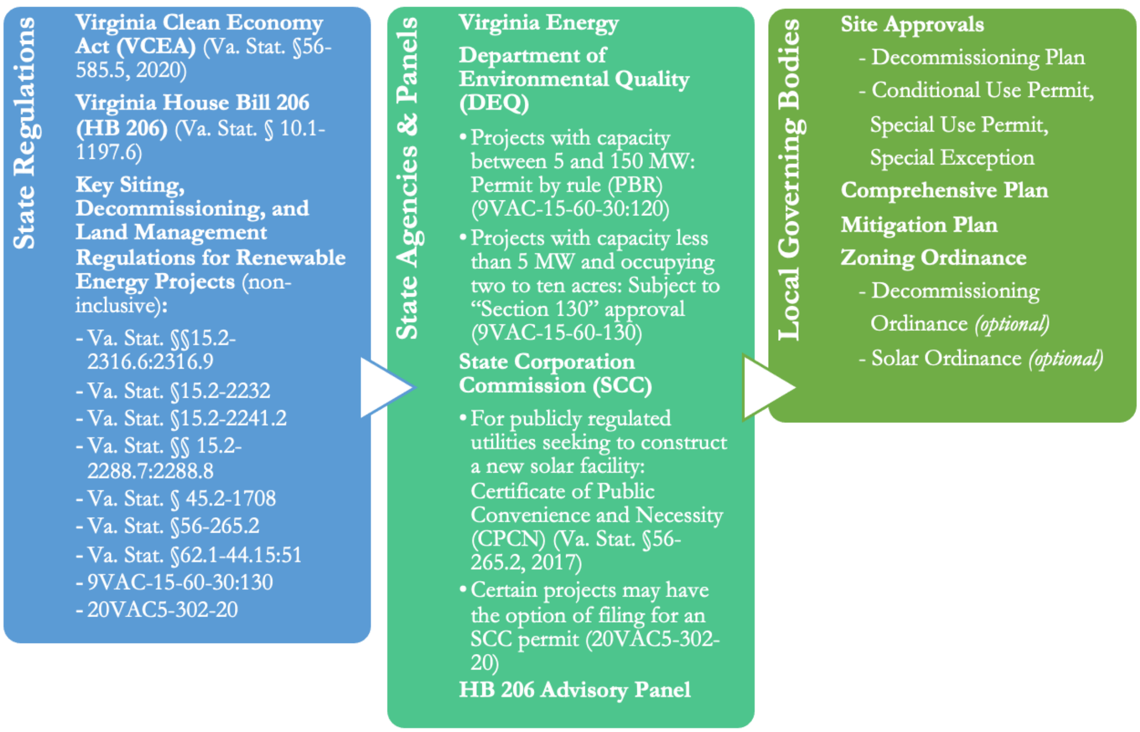
In Virginia, "small renewable energy projects" include facilities where (1) solar or wind sources generate 150 or fewer MW of electricity; (2) hydroelectric and geothermal sources generate 100 or fewer MW; or (3) biomass, waste energy, or municipal solid waste projects generate 20 or fewer MW (Va. Stat. §10.1-1197.6, 2017).

Under Virginia's dual regulatory structure, solar projects receive approval from state agencies and local governing bodies, who are responsible for enforcing both state and local solar regulations and possess the authority the regulate proposed sites beyond the requirements of state law (Va. Stat. §15.2-2241.2, 2019; Va. Stat. §§15.2-2288.7:2288.8, 2021; Va. Stat. §§15.2-2316.7:2316.9, 2021). **Figure 2** summarizes Virginia's broader governance structure for new solar energy projects.

As of April 2023, the Virginia Department of Environmental Quality (DEQ) grants a permit by rule (PBR) to utility-scale solar projects with a nameplate capacity between 5 and 150 MW. Developers' PBR applications must include an air quality analysis, assessments of cultural, wildlife, and natural heritage resources, a site and context map, a public comment period, and a certification of local government approval (9VAC-15-60-30:120). Solar energy sites with a capacity less than five MW and occupying between two and ten acres undergo a less intensive approval process known as "Section 130" (9VAC-15-60-130). Depending on the developer's preferences and whether a publicly regulated utility such as Dominion Energy or Appalachian Power Company (ApCo) is involved, a developer may instead file for a State Corporation Commission (SCC) permit (20VAC5- 302-20).

As part of the 2050 carbon neutrality goal for the Commonwealth's investor-owned utilities, the Virginia Clean Economy Act (VCEA) sets a target for Dominion and ApCo to produce 16.1 gigawatts of electricity generation from solar and onshore wind facilities (Va. Stat. §56-585.5, 2020). If Dominion or ApCo seek to establish a new solar facility rather than negotiate a power purchase agreement (PPA) for an existing facility, they must file a Certificate of Public Convenience and Necessity (CPCN) with the SCC.

FIGURE 2: Governance map of hybrid regulatory structure for solar energy development in the Commonwealth of Virginia

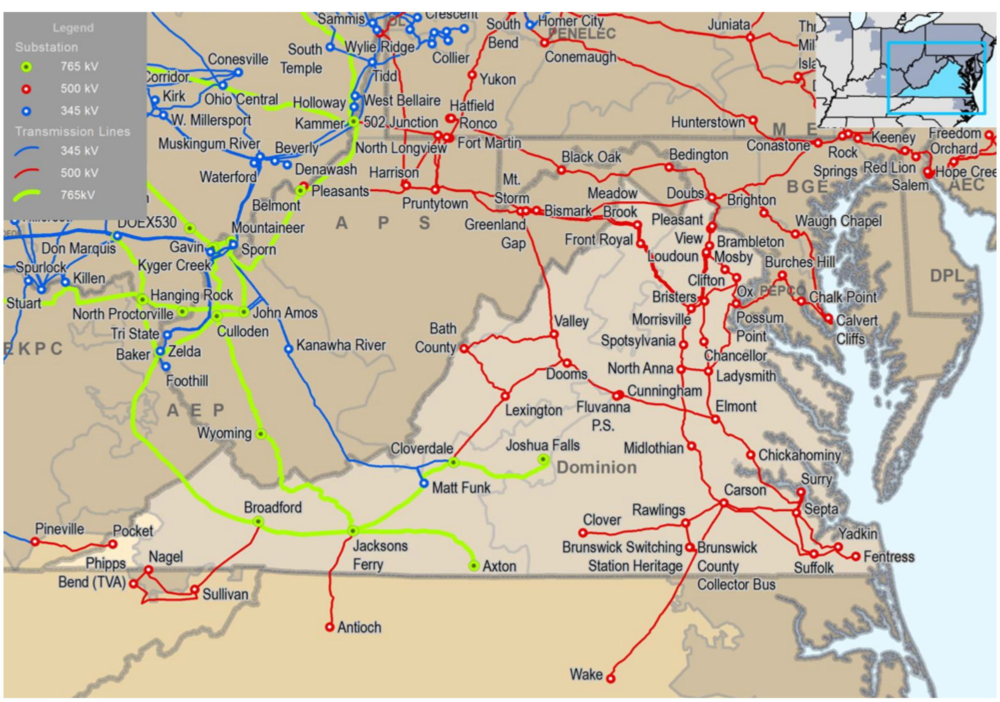


House Bill 206: Motivations and Reception

Prior to HB 206, Virginia localities identified economic benefits and land-use changes as areas where the Virginia Department of Energy could provide additional guidance. The Virginia Solar Survey, conducted in the summer of 2021 and released in April 2022, indicated that local governments' greatest area of interest concerning large-scale solar installations (i.e., sites generating one or more megawatt of electricity) was the valuation of "local economic benefits and physical development impacts" (Marshall et al., 2022, p. 12). Nearly 82 percent of the 133 localities who responded to the Virginia Solar Survey ranked the valuation of economic benefits at an average interest level of 3.57 out of 5—the highest collective ranking of any large-scale solar consideration presented in the survey. Sixty one percent of respondent localities demonstrated "a lot of interest" or "the most interest" in economic considerations. More than half of respondents—particularly rural localities—also noted "a lot of interest" or "the most interest" in understanding the impacts of large-scale solar development on agriculture and farmland (Marshall et al., 2022, pp. 34-35).

These statistics partially reflect the rural-urban divide associated with renewable energy development in Virginia. The independent regional transmission organization PJM manages Virginia's electric grid, including the higher voltage, non-residential transmission lines which efficiently dispatch energy throughout the grid across Dominion Energy's, ApCo's, and various electric cooperatives' service areas and beyond the Commonwealth, as shown in **Figure 3** (PJM, 2017; Shanmugasundaram, 2021).

FIGURE 3: Virginia Transmission Lines in PJM Service Area (PJM, 2017)



Based on viable interconnection points to Virginia's transmission lines and the optimal site characteristics sought in potential land parcels for large-scale solar projects, proposals for solar installations are primarily directed toward rural host localities. With the VCEA, a Democrat-sponsored bill, enacted on party lines with only two Republican representatives supporting, and Republicans tending to represent Virginia's rural counties (Vogelsong, 2021), partisan divides on decarbonization happen to align opposite the rural-urban split in large-scale solar facilities' siting. State-level representatives for rural localities have expressed concerns that large-scale solar projects threaten their counties' social character and agricultural economic structure (Adams, 2021). HB 206 has been characterized in part as a somewhat bipartisan—though primarily Republican—response to these land-use concerns (Vogelsong, 2022; LegiScan, 2022).

Effect of HB 206 on Solar Regulations

No structural changes to the PBR, CPCN, and "Section 130" processes have yet occurred as a result of HB 206. The Solar Regulatory Advisory Panel's December 2022 report of findings to Governor Youngkin indicated that binding recommendations remained under development: Sustained stakeholder disagreement throughout the consensus-building process indicated a strong need for continued dialogue in defining key enforcement provisions of HB 206, including the terms "avoid", "significant adverse impact", "publicly available", and "disturbance".

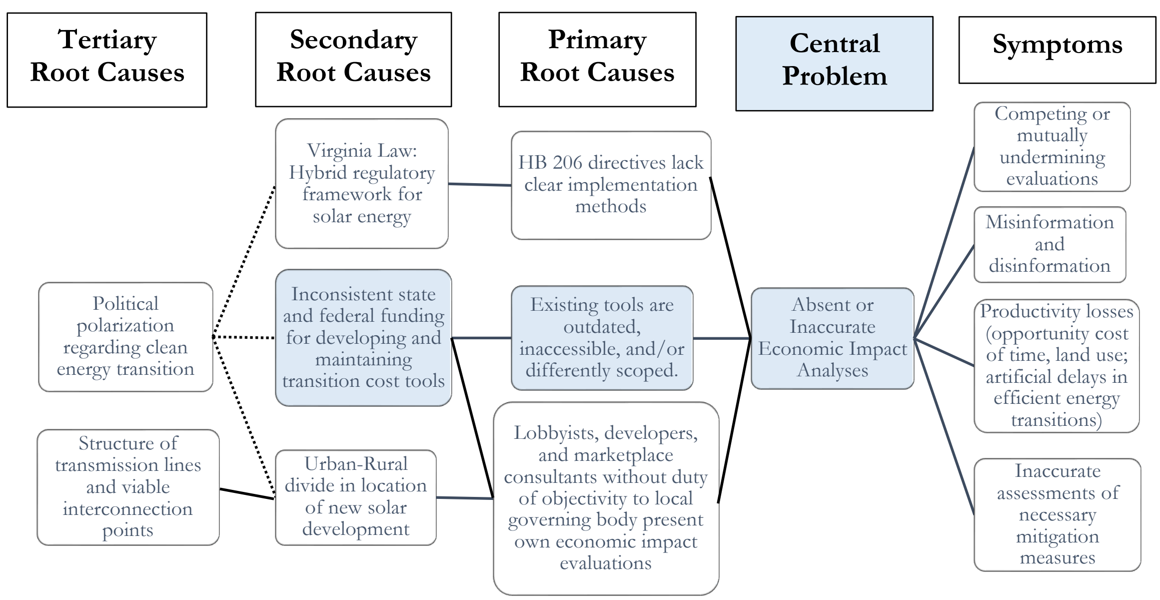
Because HB 206's main regulations cannot take effect until DEQ adopts the implementation guidance agreed upon by its advisory panel, DEQ intends to re-convene the advisory panel at a future date, as a final regulation must take effect in December 2024. In the interim, economic impact analyses—where conducted—will continue factoring into local governing bodies' renewable project approval and local permitting decisions, and solar developers may continue submitting their own EIAs to DEQ as a component of the simultaneous, state-conducted PBR process. In any case, stakeholders do not expect implementation guidance to clarify methods for evaluating the regional economic impacts of land conversions (E. Marshall, personal communication, October 12, 2022).

Causes of Insufficient EIAs

Economic impact analysis is not, as of April 2023, a required application component to state or local authorities for proposed solar facilities, but one in three Virginia localities responding to the 2021 Virginia Solar Survey reported considering or reviewing at least one economic impact analysis related to solar development (Marshall et al., 2022, p. 146). Economic impact analyses are widespread but not necessarily widely performed. Furthermore, the lack of guiding practices for conducting regional economic impact evaluations increases the risk that they are inappropriately calculated. As **Figure 4** conveys, this (1) manifests itself as competing evaluations suggested by different groups, (2) inhibits developers' ability to create sufficient mitigation plans, (3) reduces productivity as state agencies, awaiting guidance, pause site approvals and as developers delay proposals in an effort to adapt to unclear state regulations, and (4) increases sector-specific misinformation and disinformation regarding appropriate calculations of economic impact.

Where economic impact analyses exist, inaccuracies are frequently the result of existing input-output (I/O) models' complexity, obsolescence, or macroeconomic scope. Regional I/O tools apply the same basic methodologies as large-scale models but require more granular data and considerations of feedback across regions, which are not necessarily structured into the most accessible models. In addition to insufficient access to I/O toolkits, competing interests among the various parties to the permitting process can lead to economic impact evaluations with different conclusions.

FIGURE 4: Root cause analysis – Insufficient economic impact analyses of land conversion for solar energy generation in the Commonwealth of Virginia



Consequences

Direct Costs

Conducting regional EIAs and appropriately interpreting their results impose material and temporal costs on the stakeholders to site approval processes, but it is unclear how many economic impact evaluations Virginia solar developers, interest groups, or local governing bodies undertake annually to evaluate the effects of proposed land conversions. Despite this gap in state-specific data on time and resource expenditure, IMPLAN software, considered the industry standard for regional I/O analysis, is likely the most applied EIA mechanism. Cost estimates under IMPLAN and other marketed EIA software are projected in greater detail in the Analysis of Alternative 1 under the Findings and Recommendations component of this paper.

Costs of Inaccurate Information

Regulatory gaps in guidance for economic impact analyses generate inertia among local governing bodies, threatening to delay the Commonwealth's publicly codified energy transition and imposing inefficient barriers on solar projects which would be economically feasible. Because increases in solar generation may reduce energy costs to Virginia ratepayers (Creutzig et al., 2017) and have direct and indirect effects on jobs (Hondo & Moriizumi, 2017; Markaki et al., 2013), inaccurate impact analyses which halt viable projects impose costs not merely on solar developers and site owners, but on the Commonwealth as whole. Factoring Virginia's considerable dependence on energy sources involving carbon combustion, which exacerbates anthropogenic climate change, delays to decarbonization fail to avert harm to current and future generations within and beyond the state.

Analyses of economic impacts may consider some aspects of environmental quality, but do not necessarily factor institutions such as property rights (Sinden & Thampapillai, 1995, pp. 13-14). Inaccurate analyses presented under the current system and lags in implementing HB 206 may also impose negative externalities on private landowners by constraining or delaying their ability to use property as desired.

Opportunity Costs

Converting prime agricultural lands or forested property to solar generation causes society to bear non-monetary costs of lost productivity and environmental quality. It is not evident that current input-output models systematically underestimate the positive linkages generated from converting prime agricultural land, but the ecosystem benefits of maintaining forested lands are overlooked in economic impact analysis and are better represented in state-mandated environmental impact assessments.

Land restoration and dual-use generation may reduce the opportunity costs of land conversions. Evaluations may overstate the opportunity costs of converting forested and prime agricultural land to solar generation, disregarding developers' high capacity to mitigate land degradation through native plantings, end-of-life decompaction and tillage, and soil reconstruction practices. These are well-established in agronomic literature, and can restore forested soils and perhaps eighty to ninety percent of prime agricultural lands' previous productivity (L. Daniels, personal communication, July 5, 2022). Dual-use production is also feasible through allowing grazing animals on-site, given sufficient panel height (Kampherbeek et al., 2023), and agri-photovoltaic practices, or "agrivoltaics", by which harvestable crops are planted under or around solar arrays. The National Renewable Energy Laboratory emphasizes a continued need for research on the site-specific tradeoffs between a higher net land use of solar arrays versus vegetation, as energy-centric, vegetation-centric, and integrated vegetation-energy-centric approaches to colocation could have different economic effects (Macknick et al., 2013). Studies suggest farmers' take-up of agrivoltaics is based on profit maximization, environmental concerns, network effects, and ethical considerations (Brudermann et al., 2013, Farja & Maciejczak, 2021). NREL studies and ongoing research at Virginia Tech further suggest that agrivoltaic practices may further reduce previously estimated net losses in land productivity (Dreves, 2022; Macknick et al., 2022).

Utility-scale solar facilities' presence on forested lands may be overstated politically... A 2021 analysis found forests accounted for 58% of prior land cover among Virginia's utility-scale solar facilities in operation at the time.[3] Of the forested lands converted to solar generation, the Virginia Department of Forestry's Forest Conservation Model classified about 60% along the lowest conservation values of "average" or "moderate," and less than 6% at the highest designation, "outstanding" (Berryhill, 2021, pp. 23, 27).

... but disturbances to forested lands may be undervalued economically. A 2020 Economic Impact Analysis from the Virginia Department of Planning and Budget, executed at the request of the DEQ, Department of Conservation and Recreation, and Department of Forestry, suggested the economic and environmental impacts of proposed solar projects on forest lands east of I-95 were of "vital importance" and "should be assessed during the project development process" (2020, p. 7). But because EIAs track capital flows, considering backward and forward linkages across industries, they will assign greater value to lands used for silviculture than to non-commercial forested land, or otherwise calculate the harvested value of non-commercial forests (Dean et al., 1973). The shadow prices of carbon sequestration and maintaining other ecosystem benefits, such as habitats and biodiversity, are difficult to quantify, and scholars debate whether or to what extent they should factor into economic impact evaluations (Psaltopoulos & Thompson, 1993; Wang et al., 2016). Solar facilities are similarly undervalued where they avert carbon emissions that other energy technologies would have produced but the social cost of carbon remains unfactored. In fact, a recent analysis suggests a single acre of solar panels in Virginia would offset about 150 times more carbon dioxide annually than an acre of forested land (Eisenson, 2022). This raises the tangential consideration that accounting for the broader social benefits of environmental quality may be out of scope of a local or regional impact assessment.

[3] The Virginia Statewide Landcover Dataset (VaLCD), managed by multiple state agencies, defines "forest" land cover as areas of at least 30% canopy cover of woody vegetation, greater than one acre in size (Berryhill, 2021, p. 23)

Synthesis of Evidence

Virginia Land Conversions in Siting Utility-Scale Solar

Throughout the Southeast, an estimated 8.96% of localities' lands are actively devoted to agricultural use, and about 0.05% to solar (Wyatt & Kristian, 2021). Virginia's land use appears to differ from this estimate across both metrics. A recent analysis of the Virginia Land Cover Dataset found 24.9% of the state is classified as cropland—that is, cultivated or managed for food, feed, or fiber production—and 7% as hay-land or grazing pasture (Berryhill, 2021, p. 23). The Virginia Agricultural Model assesses more than a third of the state's cropland hold a "high suitability" (Class V) rating, as defined in terms of soil suitability, current land cover, and the distance between agricultural products' points of harvest and consumption (Department of Conservation and Recreation, 2015), and Berryhill's analysis suggests nearly 61% of the state's Class V farmlands—which include prime agricultural soils (Bucklin, 2019)—were impacted by solar development as of May 2021 (p. 28). Under the liberal assumption that a solar facility requires ten square acres of land to generate one megawatt of electricity (Ong et al., 2013), a rough estimate thus suggests up to 0.1% of Virginia's land may be used by operating utility-scale solar facilities (EIA, 2023).[4]

Considerations Across Analogous Land-Use Conversion Contexts

The U.S. Department of Agriculture (USDA) reports that while the amount of land used for crop production remained relatively stable between the 1980s and the early 2000s, the characteristics of land used for agricultural production changed, with higher quality soils maintained for cultivation (Lubowski et al., 2006, p. 4). The rate of conversion of agricultural and forested lands to developed uses began steadily decreasing in the late 1990s before plateauing from 2010 to 2015 (Bigelow et al., 2022, pp. 5, 3). It is unclear if these national trends have continued over the past two decades, if they reflect Virginia's average land use changes for solar energy production, or if prime agricultural lands converted from crop production are equally or more sensitive to causing environmental effects as areas at the extensive margin of cultivated land—that is, those lands most susceptible to conversion from agricultural to other uses—but solar developers have a high capacity to mitigate any such adverse environmental effects (Dubey et al., 2013, p. 333).

Furthermore, the USDA's identification of a strong association between sloped lands and the extensive margin may not be generalizable to conversions of land for solar generation, as developers prioritize potential sites which would require minimal grading. However, recent analysis suggests marginal lands have a high renewable energy potential, particularly for solar generation (Milbrandt et al., 2014; The Nature Conservancy, n.d.). The identification of soil erodibility, nutrient leaching, runoff, and encroachment on species habitats as key environmental factors when land-use changes occur remains relevant to mitigation considerations, but not necessarily to regional economic impact analyses (Lubowski et al., 2006, p. 3).

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[4] **Calculation:** Product of the sum of nameplate capacities of operating utility-scale solar facilities as of February 2023, and ten acres per megawatt = 28,310 square acres; Virginia is about 27,375,488 square acres. 28,310/27,375,488 * 100 = 0.103%.

Mechanisms for Measuring the Regional Economic Effects of Land-Use Conversions

The following analysis highlights challenges and areas for convergence across existing EIA tools because standardizing practices can powerfully resolve uncertainties surrounding competing information, introduce objective information to deliberations potentially susceptible to partisan biases, and increase EIA accessibility for multiple stakeholders. Although other research areas such as the expense of revitalizing Virginia's energy grid or encouraging a distributed generation framework deserve attention, they require capital investments and time horizons beyond those attainable in an MPP capstone project and external to the client's capacity and requests.

As summarized in **Figure 5**, each of these mechanisms analyzed indicates the impacts of a given land conversion with varying degrees of complexity and relevance.

FIGURE 5: Overview of Potential Impact Measurement Mechanisms

Mechanisms	Description	Complexity	Geographic Scope
CGE Model	Uses extensive economic data to capture detailed, long-run, statewide effects of land conversion to solar generation.	Highly complex. Operated by economists.	Statewide.
I/O Model	Provides a mixed macroeconomic and microeconomic indication of the short-run direct, indirect, and induced effects of land-use changes. Structured on demand-side changes.	Moderately to highly complex. Generally operated by economists.	Regional: One or more localities.
Economic Impact Estimate Calculator	Formulaic calculator runs input-output analysis from limited user inputs to provide a rough estimate of regional economic effects.	Low to moderate complexity. Operable by public.	Regional: Software may be state-specific or locality-specific.
MCDA Model	Creates a digital visualization of optimal sites for solar facilities based on environmental factors. Does not quantify regional economic impacts.	Low to moderate complexity. Operable by public.	Variable. Property Specific to Statewide.

Computable General Equilibrium (CGE) Models

CGE models are computer-based macroeconomic calculations usually run prior to a policy change to quantify how the payments in a social accounting matrix—the flows of money through a statewide or national economy—would likely change in response to altering an economic parameter or factor of production, including land, labor, or capital (Raihan, 2008, pp. 4, 10).
Where I/O models are structured on demand-side changes, CGE models account both for changes in supply and demand and capacity constraints, thereby including price changes over time. CGE models have a longer-run focus than Dynamic Stochastic General Equilibrium models, which focus on short-run economic effects and business cycle fluctuations, and, unlike partial equilibrium models, account for interactions and feedback between economic sectors (Chief Economist Directorate, 2016).

Scotland's CGE model could provide a useful analog for the development of a CGE model for the Commonwealth of Virginia, as the Scottish economy is roughly half the size of Virginia's and operates using I/O tables and a National Accounts dataset similar to regional data available in Virginia. A Virginia CGE model would treat other American states as exogenous regions, just as the Scottish CGE model values economic interactions with Great Britain as imports and exports.

A CGE model could offer a remarkably clear picture of the total effects of converting forested and prime agricultural land to solar generation statewide, but not without great effort: Because CGE models assume perfect competition, are sensitive to imports, exports, and their elasticities of substitution, and assume factors of production do not move across model boundaries (here, state lines), a Virginia model could prove quite challenging to code accurately (Raihan, 2008, p. 12). It would also apply statewide rather than at the county-level, would likely take more than a year to develop, and could require several weeks to generate a result for a given supply or demand change (Chief Economist Directorate, 2016). If created, such a model would require robust, regularly updated economic data and due to its complexity, would likely need to be operated by an economist.

Input-Output Models

Regional input-output (I/O) models provide a mixed macroeconomic and microeconomic indication of land-use change effects. Common I/O analyses include RIMS-II, REMI, and IMPLAN models. RIMS-II models are based primarily in national data and may overlook county-level impacts, whereas REMI models yield high accuracy at prohibitive expense. IMPLAN software is already the industry standard, and could facilitate uptake if best practices are provided, but past studies warn of its susceptibility to incorrect application.

Regional Input-Output Modeling System (RIMS-II) Data and Methods

The RIMS-II input-output model, a relatively low-cost tool developed in the 1970s, is based on a series of manually added multipliers that reflect the local economic linkages of earnings, outputs, and jobs. It is insensitive to economic feedback across regions (Neill, 2013). These regional multipliers are generated by isolating geographically relevant data from the national I/O table published by the Bureau of Economic Analysis and applying the Leontief inversion approach, a mathematical technique based in matrix algebra (U.S. Bureau of Economic Analysis, n.d.). A review of RIMS-II multipliers' effectiveness indicated accuracy within five to ten percent of more sophisticated models' statewide analyses (Lynch, 2000, p. 5), but it is not clear if this level of accuracy holds for local estimates.

Regional Economic Modeling, Inc. (REMI) Tools

REMI tools render highly precise economic impact estimates by combining econometric models with I/O analysis, making them extremely expensive and thus reducing accessibility to stakeholders. REMI relies on BEA data on employment, wages, and salaries, the Census Bureau's County Business Patterns data, and ES-202 establishment employment and wage data, considering output, labor and capital demands, population and labor supply, wages, prices, and profits, and market shares (Lynch, 2000, p. 9). A dated meta-analysis of modeling results suggests a five to fifteen percent difference in multiplier values across IMPLAN and REMI evaluations, but generally comparable final results (Rickman & Schwer, 1995, p. 146). The accuracy of both models has likely increased over time.

Impact Analysis for Planning (IMPLAN) Modeling Software

Due to its relative affordability, comprehensive datasets, and ability to parse the total effects of supply shocks into direct, indirect, and induced impacts, IMPLAN software is a highly popular mechanism for conducting economic impact evaluations (T. Rephann, personal communication, October 13, 2022). A literature review of methods for measuring the effects of agriculture on the economies of individual mid-Atlantic states found that nearly 85 percent of input-output based studies used IMPLAN (Leones et al., 1994), indicating the software may offer high familiarity and relevance for analyzing the economic effects of converting prime agricultural lands to solar generation.

IMPLAN is not, however, instantly applicable for regional economic impact evaluations: Regional economists and IMPLAN staff alike encourage analysts apply a "hybrid approach" to supplement the software's annually updated regional data with relevant local data (IMPLAN Data, 2019; Steinback, 1999). Moreover, one of IMPLAN's central simplifying assumptions—the use of sector-specific, weighted national averages to generate the production coefficients and regional purchase coefficients (RPCs) on which input-output models hinge—skews toward representing the highest spenders rather than the actual purchasing behavior of involved regional businesses, unless the analyst collects local primary cost data (Steinback, 1999, p. 729). Regional purchase coefficients themselves may vary depending on which economic sectors are included in the definition of "prime agricultural" and "forested area" business associations—an issue of subjectivity raised decades ago in the varying definitions of "agriculture" across EIAs. Poorly defined sectors or over-reaching inclusions of intermediate demands within agricultural sectors risk incorrectly counting indirect effects (Tanjuakio et al., 1996). However, I/O techniques and data have progressed over the last two decades, potentially reducing the risk that inaccurate data are applied: Even since the beginning of 2022, IMPLAN software includes fifteen new capabilities, as well as more specific occupational and environmental data (IMPLAN Representative, personal communication, April 5, 2023).

Because laypeople could misinterpret the results of regional EIAs, some reports encourage analysts to both discuss IMPLAN models' ratio multipliers in context and define induced, direct, and indirect effects (Steinbeck, 1999, pp. 732, 734; Tanjuakio et al., 1996, p. 49).

NREL Jobs and Economic Development Impacts (JEDI) Tool

The U.S. Department of Energy's National Renewable Energy Laboratory (NREL) publishes several free models intended to offer a highly accessible, web-based interface for state-level economic impact analyses of electric utility development. Users enter site-specific data and receive an estimate of direct regional economic effects based on calculations using IMPLAN I/O tables (National Renewable Energy Laboratory, 2009; Jenniches, 2018). Over the last decade, JEDI models' focus has expanded from wind energy to several renewable and non-renewable sectors, and the current solar energy impact calculator is more specific to distributed generation, such as rooftop solar installations and lower-capacity facilities which provide electricity directly to end-use consumers rather than electric utilities (National Renewable Energy Laboratory, 2021).

Multi-Criteria Decision Analysis (MCDA) Models

Combining MCDA techniques with spatial analysis through Geographic Information Systems (GIS)-based and Spatial Decision Support Systems software provides opportunities to optimize solar siting using regional data on geographic, socioeconomic, land-use, and concentrated solar power characteristics (Wanderer & Herle, 2014; Ruiz et al., 2020; Sánchez-Lozano et al., 2013; Anwarzai & Nagasaka, 2017).

Web-hosted GIS models' accessibility suggests that modifying MCDA frameworks to assess economic linkages could be a relatively simple way to help developers and localities visualize the economic suitability of some forested or prime agricultural lands for solar generation. MCDA models do not generally demonstrate regional economic impacts, but they often depict environmental sensitivities (Hernandez et al., 2015) and social impacts (Estévez et al., 2021), and can provide useful evidence of the viability of proposed solar sites. MCDA models may also use several of the same input parameters as I/O models (Wanderer & Herle, 2014). Progress in MCDA models calculating the local socioeconomic and environmental impacts of using land for solar energy production versus agricultural production indicates the potential for free, easily accessible MCDA models (Sacchelli et al., 2016), but because the open-source MCDA models proposed nearly a decade ago remain unavailable, this technology may not yet be scalable. Taken in combination with their inability to assess economic impacts, MCDA methodologies are thus not considered among alternatives for implementation.

Alternatives

Alternative 1: Let Present Trends Continue.

In this baseline scenario, solar developers, community stakeholders, and interest groups would continue generating EIAs independently, without regulatory oversight or guidance from local governing bodies or state agencies. Where presented, these EIAs would continue to be produced using (1) licensed or subscription-based software, such as IMPLAN or REMI, (2) the services of for-hire analysts, generally with similar software, (3) unstandardized practices which may or may not accurately account for economic linkages, or (4) some combination of the aforementioned options. Currently and most commonly, RIMS-II, IMPLAN, and REMI input-output models can produce regional EIAs at different levels of cost to users, and with varying results and degrees of accuracy due to differences in data quality and methodology.

Alternative 2: Standardize Procedures for Regional Input-Output (IO) Analysis.

An executive agency such as DEQ, which issues PBR approvals for utility-scale solar facilities and "Section 130" approvals for smaller sites (9VAC-15-60-30:130), would publish a minimum acceptable standard for data quality, analytical scope, and calculation methods for considering supplementary EIAs valid in the state-level site approval process. Because developers face incentives to minimize temporal and fiscal costs, they would be more likely to complete a single analysis applicable across both state and local approval processes. This could eliminate false, misleading, or otherwise inappropriate analyses, allow remaining reports to be produced by technical experts, and help reduce inaccuracies and conflicting accounts of the local effects of solar energy projects. The standardization and information-sharing process would also encourage a filtering out of faulty methods without disadvantaging IMPLAN and REMI software available in the private market and improve the correct use of the BEA's RIMS-II methods and multipliers. However, if DEQ were to advocate or publish minimum acceptable standards for considering an EIA in the site approval process without these standards' codification in state law, they would likely be subject to weak or non-enforcement, particularly among local governing bodies. In either case, it remains true as of April 2023 that economic impact analyses are not a required submission component for the state-level approval of proposed utility-scale solar facilities.

Alternative 3: Develop a Statewide Computable General Equilibrium (CGE) Model.

A CGE model would calculate likely changes in the flows of money through the state economy in response to altering an economic parameter—here, land's conversion from forestry or agriculture to solar energy generation. By accounting for changes in supply, demand, and any capacity constraints resulting from a proposed land-use change, a CGE model would indicate the longer-term, statewide impacts of a renewable energy project. Given that CGE models applied in other countries generally involve a social accounting matrix, I/O tables, data on taxes, income, and expenditures, and price elasticities of demand and supply (Chief Economist Directorate, 2016), it may be challenging to identify, access, or create appropriate data sources within the Commonwealth.

Alternative 4: Expand the National Renewable Energy Laboratory (NREL) Jobs and Economic Development Indicator (JEDI) to Utility-Scale Solar Photovoltaic Projects.

An economic impact calculator would allow users to enter site-specific data to a web-hosted model and/or downloadable macro and receive an estimate of a small renewable or utility-scale solar energy project's direct economic effects in a locality or across adjacent localities. Prior JEDI models use I/O tables from IMPLAN 3 software to generate impact estimates following user inputs to a downloadable Microsoft Excel file, with the most recent photovoltaic JEDI model limited to distributed generation facilities. Similar to existing JEDI models, IMPLAN data would likely be used in the deployment of an interactive utility-scale solar tool. There has been recent interest for coordination in redeveloping JEDI or a similar model between a team of researchers at the University of Virginia's Center for Economic and Policy Studies at the Weldon Cooper Center for Public Service and NREL data scientists. The resulting economic impact calculator would not necessarily be hosted on a state agency's website, but more likely under the U.S. Department of Energy's NREL Models website.

Criteria

Energix Renewables has requested an analysis of pathways for solar developers to run or otherwise access *ex-ante* models of the likely economic effects of converting prime agricultural or forested land to solar generation. In accordance with the Virginia office's interests, its values of environmental stewardship and community partnership, and its prioritization of transparent modeling mechanisms, it assesses the following criteria as relevant to a fair evaluation of the proposed alternatives:

Criterion 1: Cost

Cost considers (i) the ***overall cost to state and local governments*** of implementing an alternative and (ii) the ***direct costs to users***, as evaluated by model pricing. Total costs are estimated to the extent possible. Preferred alternatives minimize costs to state and local governments as well as end-users. Note that further temporal and fiscal costs of collecting additional data to run an impact assessment are addressed under accessibility.

Overall cost shall be measured as the total cost of developing, housing, and maintaining the software associated with each alternative. Relevant components of this total cost estimate include the number of individuals involved in an alternative's establishment and upkeep, their labor hours and wage rates, the cost of obtaining baseline regional (i.e., statewide, local, and industry-specific) economic data from existing vendors, and the licensing and maintenance costs associated with running the model, and may be sensitive to the rate at which an alternative can be implemented.

Factoring which party or parties implement an alternative is important in determining the overall cost to state and local government, including public researchers. Thus, an alternative's development by private companies, federally funded research institutions, or nongovernmental organizations reflect would reduce overall cost to state and local governments, though total costs may be high.

Criterion 2: Empirical Effectiveness

Empirical effectiveness assesses the likely (i) ***accuracy*** and (ii) ***precision*** of EIAs generated under each alternative. An alternative's effectiveness is distinct from its anticipated take-up.

Accuracy describes how closely the EIAs generated under an alternative reflect the actual economic impacts—that is, bearing out the true economic linkages within and across localities and industries—of converting land from prime agricultural or forested use to solar generation. Higher accuracy is preferred to lower accuracy.

Precision is an ordinal measure of an EIA estimate's granularity, ranging from statewide to site-specific. Site-specific data may be more relevant to local siting and approval processes than statewide impacts, and alternatives that can capture impacts at both levels are preferable to those which indicate only one.

Criterion 3: Accessibility

Accessibility estimates the ease with which non-experts may interface with EIAs under an alternative, including stakeholder groups' ability to ***directly operate*** and ***correctly interpret*** a model. High operability is preferred to low operability, and any systemic exclusions of stakeholder groups are unfavorable. Similarly, a higher likelihood of a non-expert correctly interpreting a model's outputs—as generalized from the literature—is preferred to a lower likelihood.

Challenges (e.g., time, methodological complexity, expertise, and expense) associated with obtaining any ***additional data*** necessary to increase an intervention's effectiveness decrease accessibility. Because costs, incentives, and primary implementation groups (e.g., state agencies, market actors) vary across alternatives, alternatives that cause key stakeholders—solar developers, community members, or local governing bodies—to incur a ***subscription cost or other paywall*** to engage with an economic model will similarly receive a lower evaluation of accessibility.

Criterion 4: Administrative Resilience

Administrative resilience gauges each alternative's sustainability across political, bureaucratic, and market contexts. This criterion thus assesses ***how many people***, what ***levels of experience*** are required to keep an alternative running in accordance with its definition. It also considers the ***degree of involvement*** original developers and/or model-hosting entities may expect to have or be willing to take on for an alternative after its initial implementation, considering both the likely duration of maintenance and the extent of maintenance costs. Higher administrative resilience is preferred to lower administrative resilience.

Criterion 5: Implementation Timeline

Implementation timeline encompasses the ***anticipated rollout time to achieve operability***, measured in months. A shorter implementation timeline is favored above a longer one because of potential impacts in contributing relevant data to local governing bodies' discussions and decisions on proposed utility-scale solar facilities.

Findings and Recommendations

Four alternative approaches to conducting economic impact analyses (EIAs) are evaluated along five criteria. Alternative 4 is recommended based on its moderate to strong rankings across criteria.

Analysis

Alternative 1: Let Present Trends Continue.

Cost: The total cost to stakeholders is conservatively calculated at about $6,805.56 annually and direct costs to state and local government bodies are low or zero.

One can reasonably assume that a one-year IMPLAN subscription varies in price between $2,000 and $8,000, depending on the region for which the analyses to be conducted: single-county subscriptions are priced lower than multi-county software, with market users facing higher prices than academics (IMPLAN Representatives, personal communication, April 5, 2023). Actual modeling costs may vary further: A decade ago, the econometrically advanced single-geography REMI model applied to one industry cost $17,000, with prices not publicly listed today (Neill, 2013). Assuming prices have risen with and not outpaced inflation along the producer price index, a current REMI analysis could cost about $21,523 (U.S. Bureau of Labor Statistics, 2023a).[5] Conversely the RIMS-II data and 2023 multipliers cost $275 per region of one or more contiguous counties, but the methodology and calculations developed by the U.S. Bureau of Economic Analysis remain free and web-accessible (U.S. Bureau of Economic Analysis, 2013; U.S. Bureau of Economic Analysis, 2023).

Making the broad assumptions that (1) solar developers or community groups presented one accompanying EIA to the local governing body for one fourth of Virginia's ninety-six solar projects currently operating or in regulatory approval and construction phases, (2) each of these projects took about two years to receive local approval, yielding a nine-year timeframe for cost analysis (i.e., 2014 to 2022), and (3) each EIA was generated through the purchase of an annual non-academic IMPLAN subscription at $5,000 (the average of the estimated non-academic range, approximating multi-county analysis), Virginia end-users' total annual spending on market EIA products could be about $13,611.11,[6] not factoring the opportunity cost of these groups' time or additional administrative costs (e.g., for contracting out services or obtaining additional input data).

Empirical Effectiveness: Empirical effectiveness is moderate to low. Where undertaken, EIAs generated in the current context may not necessarily reflect the actual economic linkages within and across localities of converting land from prime agricultural or forested use to solar generation and could thus display moderate or low accuracy. Existing EIAs vary in focus between statewide and county-level impacts, such that precision—here defined as the level of analysis—varies across project proposals.

Accessibility: Present trends are assessed as the least accessible alternative for all stakeholder groups due to prohibitively high subscription costs (Neill, 2013). This may reduce the use of fee based EIAs

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[5] **Calculation:** [(2013 price) / (Feb. 2013 PPI)] * (Feb. 2023 PPI) = 2023 price; i.e., [($17,000/(204.3)] * 258.652 = $21,522.68

[6] **Calculation:** {98 projects * 0.25 EIA rate * [($2,000 + $8,000) / 2]}/(9 years) = $13,611.11 per year

generally—resulting in fewer total EIAs relative to other alternatives—and disproportionately restrict such models' use to well-financed stakeholder groups, decreasing equitable access. Regional EIAs are highly complex (Hewings, 2020, p. 47), and past literature has noted concerns that laypeople and government officials incorrectly interpret I/O model outputs (Steinbeck, 1999, pp. 732, 734; Tanjuakio et al., 1996, p. 49).

Administrative Resilience: Present trends display high administrative resilience, based on the findings of the December 2022 HB 206 advisory group report, inactivity on solar policy through Virginia's 2023 Legislative Session, and low expectations that eventual HB 206 enforcement guidance will prescribe requirements for economic impact analysis. Under present trends, no additional state agency workers with specific expertise are involved in solar generation and land conversion EIAs. These conditions render bureaucratic processes and the overall administrative feasibility of status quo market options unlikely to change.

Implementation Timeline: 0 months; a continuation of the baseline context is effective immediately.

Alternative 2: Standardize Procedures for Regional I/O Analysis.

Cost: Overall costs could increase slightly relative to Alternative 1 due to heightened administrative costs with a marginal or non-effect on state agency employment. The Virginia DEQ's Environmental Specialists, salaried at approximately $57,000 per annum, issue state-level regulatory approvals for solar projects (Glassdoor, 2023; DEQ, 2023). Assuming the same office shares best-practice information or publishes a directory of already established resources on regional I/O models (EPA, 2000; Gunton et al., 2020), hiring, salaries, and government expenditures on employee benefits would be unimpacted, but administrative costs may increase. Given that DEQ maintains a publicly accessible website, the costs of obtaining a domain, hosting the full site, and installing a secure sockets layer certificate need not be factored (Hoory & Bottorff, 2022). The size of DEQ's established site suggests the addition of another page or link on a page would not significantly increase web design or maintenance costs, which likely come at a set price for a threshold of web pages (Leonard, 2023). If posting best-practices requires publishing an additional webpage on the DEQ site, this could cost about $100 (Brinker, 2023).

The standardization and information-sharing process could discourage faulty methods without disadvantaging private market EIA tools. Thus, end-user costs would remain about $5,000 or more per regional analysis.

Empirical Effectiveness: Moderate to low. EIA accuracy may improve slightly from the baseline *if take-up is high* due to effective local partnership, strong public communication, and/or legal authority. DEQ rulemaking or legislative enforcement would generate stronger accuracy effects than a public promotion of EIA guidelines, particularly as DEQ has noted that "the absence of certain timeframes [for solar developers]" in the PBR process complicates their enforcement ability and "hinders their ability to ensure good practices" (Virginia Department of Planning and Budget, 2020, p. 12). Assuming a similar lack of enforcement power, inaccuracies in calculations may persist, and the granularity of EIAs could remain variable—statewide or site-specific—again rendering effects on precision ambiguous.

Accessibility: This criterion ranks low to medium. Under high take-up of recommended methods, stakeholders may be more empowered directly operate free models and more likely to correctly interpret model outputs in context, regardless of their accuracy. However, if DEQ communicates procedures but stakeholders do not receive or act upon them, operability and interpretation will remain unchanged from the baseline; thus, it is not evident that sharing standardized procedures would increase decisionmakers' and model users' fluency with EIAs over time. In either case, marketed EIA options would remain commonly used, with paywalls reducing overall ease of access.

Administrative Resilience: High. This would likely have a marginal or non-effect on state agency employment and by extent salaries paid, though an increase in labor hours during initial deployment as staff members coordinate with economists and regional organizations to share information could increase bureaucratic frictions against action. Once guidelines are publicized, there is not a strong need for state agency workers to possess expertise on best practices, exercise a high degree of monitoring and oversight, or incur maintenance costs to keep information current, as conclusions on good practices remain consistent across decades (EPA, 2000; Williams, 2019).

Implementation Timeline: 6 to 8 months. DEQ would post regional economists' clarification in non-technical language of I/O good practices online. Should DEQ further partner with an organization such as VACO to encourage localities to hold to these improved standards for admissible empirical evidence, implementation would last longer but empirical effectiveness could be more likely to increase, as a recent meta-analysis of the literature (Gil-Garcia & Sayogo, 2016) suggests intergovernmental information-sharing and coordination among public sector groups can enhance efficiency.

Alternative 3: Develop a Statewide CGE Model.

Cost: Public research institutions and state government agencies would split a high overall development cost, with options for (1) no direct cost to end-users requesting an analysis or (2) analyses priced to recoup the license fee for developing and running CGE software. Note that maintenance costs are considerable, but weighed under administrative resilience.

At least one salaried analyst could be hired with the sole responsibility of developing, operating, and maintaining a CGE model; alternatively, the equivalent work hours of one analyst could be distributed among three to five hired experts with other responsibilities. Assume, thus, that the state government or a public university hire the equivalent of one mid-career PhD economist at a $105,630 annual salary with a 31% benefits rate—thus, at a total annual cost of $138,023—to implement and maintain this Alternative (U.S. Bureau of Labor Statistics, 2019; U.S. Bureau of Labor Statistics, 2023b). Also assume that for $1400, a research team of five or fewer members at the same public institution purchases a twelve-month multi-user/department (MUD) license at the academic rate to operate the General Algebraic Modeling System (GAMS) computer program, GAMS/BASE, and the GAMS/MPSGE solver, a very common software for CGE modeling and an alternative to the more expensive option of developing an original CGE model (GAMS, 2023; Yerushalmi et al., 2019), by month six of the buildout. If the team is non-academic, a five-member

MUD license, GAMS/BASE subscription, and GAMS/MPSGE solver would cost about $15,194 (GAMS, 2021; U.S. Bureau of Labor Statistics, 2023a).[7]

Under the conservative assumption that the rate of site proposals remains constant such that eleven CGE analysis requests occur annually for proposed solar facilities,[8] and assuming the sum of analysis fees pays for the next year's MUD license and a maintenance and support update, which is currently twenty percent of the module's list price (GAMS, 2023), "end users" (here, EIA requesters) in the academic buildout scenario would pay $152.73 per requested analysis,[9] and the initial year's post-implementation cost, if paid fully by the state government, would be at least $139,703.[10] In a non-academic CGE buildout under the same assumptions, end-users would pay about $1,657.51 per requested analysis[11] and the initial year's cost to the state government would be approximately $156,135.66.[12] Under an 18 to 30 month buildout, implementation costs would thus total $225,267.16 to $378,484.04, assuming non-academic pricing.[13]

Empirical Effectiveness: CGE modeling demonstrates the highest accuracy of all proposed alternatives and receives a strong ranking on precision, as it indicated long-run, statewide effects of site-specific changes. It does not, however, demonstrate impacts across counties.

Accessibility: The CGE model is more accessible to public officials, private citizens, and solar developers than the baseline alternative or promoting standardized procedures. Although these stakeholders cannot directly interface with the model, it is more likely that outputs will be correctly interpreted, as the CGE model's objective operating office would communicate findings to local governing bodies and/or make results publicly available.

Administrative Resilience: Low to medium. The CGE model's developer could vary: An alignment of incentives for promoting the public good and encouraging economic development suggests that a CGE model's development by a public research institution and deployment through the Virginia Secretary of Commerce and Trade's website or office—or through one of its affiliate agencies, such as the Virginia Economic Development Partnership or Virginia Energy—may be more likely than development and operation by private firms, who to-date have not established or publicly expressed interest in establishing a CGE model. Few workers and a high expertise level are required to engage this alternative, which would have high annual maintenance costs and a long duration of maintenance, particularly if the operating expert attains additional data beyond software packages or builds out the existing social accounting matrix.

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[7] **Calculation:** Non-Academic Price in April 2021 = $6,400 + $3,200 + $3,200 = $12,800. April 2023 Price = [(April 2021 price) / (April 2021 PPI)] * (Feb. 2023 PPI); i.e., [($12,800 / (217.9)] * 258.652 = $15,193.88.

[8] **Calculation:** (98 facilities / 9 years) = 10.889 proposed sites per year. Note that EIA data undercount the actual number of DEQ NOI-received facilities.

[9] **Calculation:** [1.2($1400)] / 11 = $152.73

[10] **Calculation:** 1.2($1400) + $138,023 = $139,703

[11] **Calculation:** [1.2($15,193.88) / 11 = $1,657.51

[12] **Calculation:** 1.2($15,193.88) + $138,023 = $156,135.66

[13] **Calculations:** Academic Pricing, 18-month buildout = 1.5($138,023) + 1.2($1400) = $208,714.50,
Academic Pricing, 30-month buildout = 2.5($138,023) + 2.2($1400) = $348,137.50
Non-Academic Pricing, 18-month buildout = 1.5($138,023) + 1.2($15,193.88) = $225,267.16
Non-Academic Pricing, 30-month buildout = 2.5($138,023) + 2.2($15,193.88) = $378,484.04

Implementation Timeline: Conservatively assumed at 18 to 30 months, as the state government or public institution would have to assemble a staff, purchase modeling software, and generate the statewide model. The same team could also build out additional Virginia-specific data to make the model more specific, with some time cost involved: The Government of Scotland's CGE staff also note that "new simulations can take several weeks to complete" (Chief Economist Directorate, 2016), but once a base version is established, the CGE calculations can be run relatively quickly.

Alternative 4: Expand the NREL JEDI to Utility-Scale Solar Photovoltaic Projects.

Cost: The federal government's National Renewable Energy Laboratory would primarily bear the high overall cost of expanding the JEDI Photovoltaics model for utility-scale projects nationally, with no direct cost to end-users (National Renewable Energy Laboratory, 2021). Given the likelihood of a public research institution partnering with NREL to improve the expanded model's Virginia data via research grants, private funding, and public funding, the cost to state government could be lower than the overall costs presented in the following calculations.

NREL's subscription costs and private licensing with IMPLAN to apply I/O tables in an interactive public model could cost upwards of $80,000 to $100,000.[14] Assuming again that the state government or a public university hire the equivalent of one mid-career PhD economist at a $105,630 annual salary to support this Alternative's initial buildout with Virginia-specific data (U.S. Bureau of Labor Statistics, 2019; U.S. Bureau of Labor Statistics, 2023b), the total eighteen-month to two-year implementation cost to the state government would be about $207,000 to $276,050.[15]

Empirical Effectiveness: The JEDI alternative offers moderate accuracy (National Renewable Energy Laboratory, 2015), improving with the user's addition of site-specific data, and focuses specifically on statewide economic impacts.

Accessibility: This alternative offers the highest accessibility of the four alternatives because users may engage with it directly, do not encounter a paywall, and may face greater accountability in interpreting outputs correctly because of spreadsheet-generated guidance and descriptions. Local governing bodies may directly apply the model based on developer-contributed information or may receive developers' submissions of impact estimates generated using the model.

Administrative Resilience: Medium to high. The model is not housed or operated by local or state officials, whose contributions to rollout may only include additional data provision to sharpen national accounts and IMPLAN 3 datasets. NREL's many, high-expertise workers are likely to remain well-funded over the next decade. The model's original developers need not maintain a high degree of involvement with the macro spreadsheet and/or web tool once posted online. Maintenance costs in the form of collecting and updating relevant regional data will be costly in terms of time and money. Licensing updating I/O tables beyond IMPLAN 3 in the future may also

[14] IMPLAN Representatives shared non-academic pricing for a national subscription, but this market cost data is proprietary.

[15] **Calculation:** 18-month implementation: 1.5($138,023) = $207,034.50
24-month implementation: 2($138,023) = $276,046

be expensive, but would be covered by the federal government, reducing administrative burdens on the state and local public sector.

Implementation Timeline: Assumed at 18 to 24 months. Model buildout could be shorter than under a CGE model because the existing distributed generation photovoltaics model offers a useful template with several shared industry linkages. It may also be feasible to further incorporate an earlier pilot model, the PV Project JEDI for residential, small and large commercial, and utility-scale sites (Friedman, 2012). Rollout time will depend on Virginia-based researchers' ability to coordinate successfully with NREL scientists and receive requested data from state agencies and relevant industry representatives.

Outcomes Matrix

The following matrix summarizes alternatives' rankings across evaluative criteria. Deeper color gradations indicate preferable criterion rankings. Color gradients are assessed vertically across alternatives rather than horizontally across criteria; thus, "Medium to High" in one criterion category may take a stronger hue than "Medium to High" in another category based on the estimated impact of other alternatives. Note that no suggested alternatives restrict stakeholders' ability to use private market models.

Alternatives	**Evaluative Criteria:** Cost	Empirical Effectiveness	EIA Accessibility	Administrative Resilience	Implementation Timeline
Present Trends Continue	**Overall Cost:** Unknown, borne by market. No direct cost to state and local government. **Direct User Cost:** About $5,000 or more per EIA subscription.	Lowest to Medium Accuracy and Variable Precision (Variable Focus)	Low	High	0 months
Standardize Regional I/O Procedures	**Overall Cost:** Present Trends + State Gov't Administrative Costs; About $100 in additional costs to state government. **Direct User Cost:** About $5,000 or more per EIA subscription.	Low to Medium Accuracy and Moderate to Strong Precision*** (Variable Focus)	Low to Medium	High	4 to 6 months
Statewide CGE Model	**Overall Cost:** App. $225,270 to $378,500, possibly split between public institutions and state gov't. * **Direct User Cost:** $0 (no fee), or $152.73 (academic fee) to $1657.51 (non-academic fee); private models still available.	Very High Accuracy Strong Precision (Statewide Effects of Site-Specific Change)	Medium	Low to Medium	18 to 30 months
Revitalize JEDI Calculator	**Overall Cost:** App. $207,000 to $276,050 to state government and public institutions; Further model buildout costs, about $80,000 to $100,000, borne by federal government. ** **Direct User Cost:** $0; private models still available.	Moderate Accuracy, Increasing with User Inputs Moderate to Strong Precision (Site-based analysis)	Medium to High	Medium to High	18 to 24 months

** - Assumes model housed/operated in state government agency.*
*** - Assumes model co-developed by federal research institution.*
**** - Improvements relative to baseline dependent on take-up and enforcement, as discussed in analysis section. This matrix assumes legislative requirements are infeasible, rendering take-up voluntary.*

Recommendation

Because **Alternative 4** demonstrates the strongest performance across all criteria, **stakeholders should coordinate with NREL to revitalize the JEDI calculator**, expanding its free, web-accessible I/O analysis to evaluate the statewide effects of proposed utility-scale solar facilities in Virginia. Although this option could take longer than a year to reach operability and is less administratively resilient than Alternatives 1 and 2, it makes generally accurate and moderately precise EIAs the most accessible of all the options to stakeholders and could thus offer a greater process gain to local governing bodies' regulatory decisions. Expanding the JEDI model would not force stakeholders to stop conducting EIAs through other market options or seeking local approvals for proposed solar facilities during or after the year to year-and-a-half buildout period. Thus, data-driven discussions of economic impacts would not inherently be absent from local approval processes over this timeframe, and Alternative 4 could provide a reasonable point of comparison for verifying the general accuracy of stakeholders' other EIAs.

Alternative 3, developing and implementing a statewide CGE model, also received strong rankings across criteria, and could be useful to implement given sufficient resources and administrative support. It would yield highly accurate results, but likely at a higher cost to the state and with a longer implementation timeline. Furthermore, because a CGE model would convey impacts on the state rather than localized impacts, it would not provide local decisionmakers with the site-specific information they've indicated is a priority.

Implementation

Implementation Plan

Analogous Pathways: Prior JEDI Models

Past NREL JEDI models for other renewable energy industries have applied similar implementation structures (Billman & Keyser, 2013, pp. 3-4): Often in combination with academic research teams, NREL interviews with project developers, industry leaders, and state taxation officials and a literature review yield technology cost data. Researchers then combine this data with IMPLAN input-output tables and state data synthesized by the Minnesota IMPLAN Group from the U.S. Census Bureau, BEA, and Bureau of Labor Statistics to draft a model subjected to internal review at NREL and the U.S. Department of Energy. After external review by both experienced users and validation by industry experts, NREL releases JEDI models online, supported by user guides, public presentations, peer reviews, software updates, and model improvements (National Renewable Energy Laboratory, 2013a). **Figure 6** scales past implementation across a potential future timeline.

FIGURE 6: Recommended Implementation Pathway

Recommended Implementation for Utility-Scale PV JEDI Model

Phase 1: Initial Coordination. In the first three months, a Virginia-based research team of economists experienced in conducting regional EIAs and NREL officials would coordinate research considerations.

Phase 2: Updating Data. Researchers would refine existing data sources on state and county-level employment, household income, and spending by businesses and households and seek out information to fill identified gaps through months three to twelve. While the updated IMPLAN 3 software's sub-national social accounting matrices contain much of this relevant information (Clouse, 2023), researchers can further refine regional estimates by determining more specific cash flow receipts for Virginia's agricultural, forestry, and solar industries. Observed jobs data is a known area for improvement and validation (Billman & Keyser, 2013, p. 6).

Phase 3: Hard-Coding and Ground-Truthing. In months ten to fifteen, NREL scientists would update data from the JEDI model for distributed solar generation to reflect state and country-level regionality and economic linkages. They would create more specific, site-based prompts for user input, providing statistically probable ranges of values, where feasible, if end-users are unwilling or unable to enter their own information. Consistent with JEDI standards, NREL would then subject the drafted model to internal and external reviews to verify accuracy between months twelve and eighteen, revising as needed.

Phase 4: Public Rollout. By month eighteen, NREL would post the final Utility-Scale PV Model to the publicly accessible JEDI webpage. In the following months, Virginia-based researchers—and potentially the Client, Energix Renewables—could encourage developer take-up through coordinating with industry leaders, non-governmental organizations, and state officials, as described below. NREL and Virginia researchers would implement update and maintenance standards for the expanded model, perhaps every three to five years for state data, as is commonly practiced for regional EIA updates, and annually or with the most recent available data for IMPLAN software.

Stakeholders and Responsibilities

Energix Renewables has already brought challenges associated with solar developers' practice of regional EIAs to the attention of an interested research group affiliated with the University of Virginia, the Weldon Cooper Center for Public Service. Coordination across Virginia universities conducting renewable energy research—notably, the University of Virginia, Virginia Tech, Virginia Commonwealth University, Virginia State University, and James Madison University—in this effort may be feasible given their recent cohesion in ongoing energy research efforts. Moreover, NREL and U.S. Department of Energy partnerships with universities in deploying and improving JEDI models are common, and not unprecedented in the Commonwealth; for example, a research team at James Madison University played an instrumental data collection and model evaluation role in an NREL analysis of the economic impacts of offshore wind in the American Southeast (National Renewable Energy Laboratory, 2013b).

NREL researchers would do well to act on their own past implementation critiques and ensure this new model (1) clearly references and documents state, sub-state, regional, and national data sources applied in the default software; (2) is accompanied by a user guide written in laymen's terms, and (3) maintains consistent terminology throughout both the model and the user guide (Billman & Keyser, 2013, p. 6).

While research teams can implement the model without necessarily engaging Virginia's state legislature or demanding state executive agencies' managerial oversight, the project cannot progress efficiently without clear and repeated interactions with state agencies and officials, such as Virginia's Secretary of Commerce and Trade, Department of Energy, DEQ, Department of Forestry, SCC, and Department of Agriculture and Consumer Services—and potentially local governments—to update relevant data. Building and maintaining trusting, forthright, professional chains of communication will facilitate data access that improves existing software.

Challenges

Communicating Empirical Supports to Local Decisionmakers

Several local governing bodies in Virginia face pressures to set—or vacillate between setting and repealing—moratoriums on solar development applications (Arrington, 2021; Thompson, 2023; Smithfield Times Editorial Board, 2023). While EIAs for potential facilities could meaningfully inform these decision-making processes, anti-solar sentiment and distrust of developers may underlie limited local engagement with objective models. Officials at the Virginia Association of Counties (VACO) and Virginia Municipal League (VML) are uniquely positioned to objectively inform local governing bodies of the model's utility and comparative advantage in providing accurate information with greater accessibility.

Mobilizing Developer Use

Sustained industry engagement with JEDI software over time demonstrate the NREL models' relevance (National Renewable Energy Laboratory, 2013a), but low solar developer take-up will limit the suggested model's effectiveness. In the past, developers have been reluctant to enter site-specific data they consider proprietary information, including crucial cost data on materials, labor, equipment, operation and maintenance, utility interconnection, easements, and permitting, and key financial parameters, such as tax status and debt to equity ratios (Goldberg et al., 2004, pp. 8-9). The proposed model thus allows a workaround: Defaulting to industry-confirmed ranges of values where end-users find data entry inappropriate, although estimates' accuracy increase with the specificity of data provided. With the Client firm's facilitation, industry guides such as the Solar Energy Industries Association (SEIA) could play a particularly useful role in conveying the modern JEDI models' security to other solar developers nationally.

Conclusion

While Alternative 4 would not necessarily expedite governing bodies' permitting decisions for proposed solar projects, the JEDI model's high accessibility, moderate accuracy, and low end-user costs could root deeper discussions of other relevant site considerations among developers, local decisionmakers, and community members in reasonably accurate data.

The JEDI alternative's past implementation pathways offer insights into coordinating future development efforts. Given Governor Youngkin's all-of-the-above approach to energy resilience (Porter, 2022a) and emphasis on empirically based regulatory review (Porter, 2022b), researchers' outreach to state agencies when developing the JEDI model is unlikely to undermine the current administration's policy priorities and should not meet staunch political resistance. Take-up, however, may be more challenging both among localities and developers and will require engaging governance organizations and industry leaders.

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