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Assessing the Economic Impacts of Sustainable Energy: An Analysis of Ohio's Community Solar Program

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Abstract: "Ensure access to affordable, reliable, sustainable, and modern energy for all" is one of the United Nations' 17 Sustainable Development Goals. A key target for achieving this goal is increasing the share of renewable energy. In the United States, many states are evaluating the environmental and economic impacts of the renewable energy transition. This study provides an in-depth evaluation of the economic impact of Ohio's proposed Community Solar Pilot Program, which plans to install 1750 MW of new solar capacity, including 250 MW on distressed Appalachian sites. We combine two input–output models to estimate the economic impact of community solar projects: the Jobs and Economic Development Impact (JEDI) model from the National Renewable Energy Laboratory (NREL) for the construction phase, and IMPLAN for the projects' 25-year lifespan. Data for this study were gathered through surveys of local solar developers, who are familiar with the regional costs of installing and operating solar projects. Our findings indicate that the community solar program could support 32,430 full-time job years and contribute USD 4.37 billion to Ohio's Gross State Product (GSP). Additionally, the program could generate USD 409.5 million in local tax revenue over its lifetime. The study highlights the potential of renewable energy initiatives to foster economic growth, particularly in economically distressed regions like Appalachian Ohio.

Keywords: input–output; solar; IMPLAN; JEDI; renewable energy; sustainable development

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1. Introduction

On 12 October 2021, Ohio's Community Solar Pilot Program was introduced to the Ohio House of Representatives during the 134th General Assembly of the Ohio Legislature. The program aims to allow the development of community solar projects (more information regarding Ohio's Community Solar Pilot Program may be found at https://www.legislature.ohio.gov/legislation/134/hb450, accessed on 8 August 2024). A community solar program is any solar project that benefits multiple customers. Typically, customers benefit from lower electricity costs through the generation of solar energy at off-site arrays. This allows customers to receive the benefits of using solar energy without the costly start-up costs involved with the installation of solar panels on personal property, such as the roofs of homes or businesses. Community solar also opens access to customers who do not own their own homes or who do not have the necessary solar resources at their location (https://www.energy.gov/eere/solar/community-solar-basics, accessed on 8 August 2024).

Ohio might not have the best conditions for solar energy generation. However, community solar programs are not necessarily established in states with optimal solar energy conditions. Michigan and New York have the largest capacity through community solar outside of Florida [1]. At the same time, The National Solar Radiation Data Base (NSRDB) indicates that both states have less solar radiation annually than Ohio.

The lack of optimal solar conditions in Ohio does not mean that generating electricity from solar panels is not beneficial or possible in Ohio. Ohio has seen solar energy investments since 2020 and currently ranks 14th for total installed solar capacity in the US. Ohio is expected to rank 7th in growth over the next five years [2]. The solar energy market in Ohio is valued at USD 4.3 billion, with USD 1.5 billion invested in 2023 alone. Ohio is also the home of First Solar, one of the largest and most advanced solar panel manufacturers in the US [2].

Although Ohio lacks the best solar energy conditions, the state has a well-developed photovoltaic supply chain. However, community solar has remained a policy issue in Ohio as the state has a strong historical reliance on traditional energy sources, such as coal and natural gas. In addition, some communities in Ohio are skeptical of the bad impacts utility-scale solar farms might have on lands and the environment [3]. Unlike utility-scale solar, community solar is a new and innovative approach that allows individuals and businesses to own or subscribe to a portion of a solar farm and benefit from the energy produced. Government incentives are necessary to promote the growth of community solar energy in Ohio. The community solar program was reintroduced into the 135th General Assembly of Ohio and is currently under review by the House Public Utilities Committee under HB197 (more information about HB197 can be found at: https://www.legislature.ohio.gov/legislation/135/hb197, accessed on 20 October 2024).

If enacted, Ohio's Community Solar Pilot Program would establish a three-pronged approach for developing community solar in Ohio. The program would allow for the installation of 1750 MW_{AC} (Ohio's Community Solar Pilot Program sets the thresholds using alternating current (AC) over direct current (DC); we use a conversion factor of 1.3 to convert AC to DC to use NREL and IMPLAN for the analysis but continue to use MW_{AC} for reporting to keep consistency with the requirements of the Community Solar Pilot Program) of new capacity, including the installation of 1000 MW_{AC} of new capacity on various site types (with a project cap of 10 MW_{AC}), 500 MW_{AC} of new capacity specifically on brownfield sites (with a project cap of 20 MW_{AC}), and additional installation of 250 MW_{AC} of new capacity will be allotted for construction in a qualifying Appalachian region site (with a project cap of 20 MW_{AC}). Qualifying Appalachian sites include brownfields, parcels in a new market tax credit area, landfills, solid waste facilities, mine-scarred lands, or lands owned by a land reutilization corporation in one of the 32 Appalachian Counties of Ohio. All construction is expected to be completed within five years. After construction is completed, each facility will have an expected lifespan of 25 years.

In 2023, Ohio's total net electricity capacity was approximately 135,810 gigawatt-hours. Of the total net energy produced, 59.4% was from natural gas, 23.1% was from coal, and 11.4% was from nuclear power [4]. Solar energy only accounted for 1% of the total net capacity produced in the state [4]. Once the community solar program build-out of 1750 MW_{AC} is complete, the program is expected to produce an additional 3000 gigawatt-hours annually or 2.2% of the current total annual capacity in Ohio, a relatively small portion (more information can be found at http://www.eia.gov/electricity/state/ohio/, accessed on 20 October 2024).

This economic impact study focuses on two aspects of the community solar program: construction and operation and management (O&M). The construction phase captures the temporary impact of the installation of each project, while the O&M phase captures the long-lasting impacts of each project over the 25-year lifespan. This analysis assumes that construction of a 5 MW_{AC} project will take six months, construction of a 10 MW_{AC} project will take nine months, and construction of the 20 MW_{AC} projects will take one year. The total construction period for all projects is no more than five years from the program's start. It is assumed that each photovoltaic (PV) installation will use monocrystalline silicon PV modules with tracking on one axis.

This study aims to estimate the potential economic impacts this community solar program may have on the State of Ohio. As solar generation expands throughout the state, other energy generation sources may decline. However, we do not model the impact an increase in solar generation will have on fossil fuel or any other source of electricity generation. Additionally, as the expansion of solar generation occurs, we expect to see shifts in employment from one sector to another rather than creating new jobs. Likewise, the same holds true for the value added to the state. As such, we consider this analysis to measure the solar program's contribution to the state of Ohio's economy.

Since the construction phase of a solar project represents the phase with the highest level of investment, this phase has the most significant impact on job creation and the local economy. We begin by estimating the potential impact of the construction and one year of operations and management (O&M) for a single project at three potential sizes: 5 MW_{AC}, 10 MW_{AC}, and 20 MW_{AC}. We then estimate the lifetime impact according to various scenarios regarding the distribution of facility size for each program section.

To calculate the impacts more precisely, we combined two methods for economic impact analysis: National Renewable Energy Laboratory (NREL)'s Jobs and Economic Development Impact (JEDI) photovoltaics model (further information about the photovoltaics JEDI model, data, and methodology can be found on NREL's website at https://www.nrel.gov/analysis/jedi/pv.html, accessed on 8 March 2023) for estimating construction impacts, and IMPLAN (further information about IMPLAN's model, data, and methodology can be found on IMPLAN's website at https://support.implan.com/hc/en-us/articles/360044985833-About-IMPLAN, accessed on 8 August 2024) for estimating the O&M of the facilities. Additionally, developers of community solar projects were surveyed in order to adjust inputs for the models to more accurately reflect the true costs associated with PV installation and operations in the state of Ohio.

The JEDI model was chosen for construction over IMPLAN as it could be tailored to the construction of photovoltaics. In contrast, IMPLAN did not have the same level of specification for their construction categories. However, the JEDI uses IMPLAN as a basis for calculating its own multipliers. IMPLAN was chosen to model the economic impact of O&M using "generation of solar power" as the specification. Both models are I-O models, or input–output models, and are, therefore, subject to the same limitations. As such, we do not consider the feasibility of construction or O&M in terms of scarcity of resources or other supply chain constraints. Likewise, the model only examines backward linkages and does not consider what happens to the product once it is sold; for example, we do not model an increase in household spending resulting from lower energy costs. Nor do we model the offset in other energy-producing sectors as a result of the community solar project (more details regarding the limitations of I-O modeling can be found at https://support.implan.com/hc/en-us/articles/115009505587-Detailed-Key-Assumptions-of-IMPLAN-Input-Output-Analysis, accessed on 8 August 2024; or at https://www.nrel.gov/analysis/jedi/limitations.html, accessed on 8 August 2024). Furthermore, sites involved with the community solar program are expected to be leased from the landowners rather than purchased. As such, we include the costs associated with leasing the land as part of the analysis. As the lease payment goes directly to landowners, it only creates the induced impact from new household spending. However, we do not model the opportunity costs associated with using the land for something other than solar generation, such as farming or agriculture for greenfield sites, nor alternative uses for distressed sites. Finally, we assume static prices for the analysis (all dollar values in this study are expressed in 2023 dollars).

Definition of Terms

Throughout this study, we use several reoccurring terms, which we define as follows:

- **Direct effects**— effects resulting from the change in activity of a specified industry or new policy, such as the Community Solar Pilot Program effect on PV construction and operations.
- **Indirect effects** — effects resulting from purchases made by the specified industries from supply chain businesses in the region (Ohio).
- **Induced effects** — effects resulting from the spending of new household income by employees of the industries affected by the direct and indirect effects.
- **Job years** — the equivalency of employment for 12 months. In cases where the job is expected to last less than one year, the reported job years are adjusted. Additionally, job years do not account for positions that last for more than one year, e.g., if the

same operations manager is employed for 25 years, it is considered 25 job years rather than one employee. Likewise, the same construction worker may work on more than one project over the construction phase as construction on one project ends and construction on another begins. By counting job years instead of new employees, we are able to mitigate this potential double counting.
- **Earnings** — The labor income, or employee compensation with benefits, including payroll taxes paid by employers and the proprietors' income.
- **GSP** — The contribution to gross state product for the state of Ohio, or the value added to Ohio.
- **Gross output** — The total value of the industries' production.

2. Literature Review

Renewable energy, particularly solar power, has gained significant policy attention in recent decades as countries like the United States aim for net-zero emissions by 2050 [5]. The renewable energy sector, especially solar, has expanded rapidly to meet this goal. For instance, the solar industry grew more between 2010 and 2020 than in the previous four decades combined [6]. Researchers have studied its economic impact through various approaches as renewable energy gradually replaces conventional fossil fuels.

2.1. Economic Impact Analysis Through Input–Output Modeling

One common method for analyzing the economic impact of exogenous shocks—such as introducing a new renewable energy source or phasing out a fossil fuel source—is input–output (I-O) modeling. This methodology "measures the relationship between a given set of demands for final goods and services and the inputs required to satisfy those demands" [7]. In simpler terms, it estimates the number of jobs created and the amount of labor income generated by a new industry. IMPLAN I-O modeling software has been widely used to analyze various energy-related economic changes. More recently, the National Renewable Energy Laboratory (NREL) has integrated IMPLAN data into its Jobs and Economic Development Impact (JEDI) models to provide more specific analyses of power generation facilities, including photovoltaics [8].

When modeling economic impacts from exogenous shocks, such as building a new industrial or power generation facility, best practices involve distinguishing between construction (temporary) and ongoing operations (recurring) impacts. Large capital investments in infrastructure during the construction phase often lead to significant short-term economic impacts that do not persist at the same level post-construction [9]. Consequently, economic impact studies generally separate construction impacts from operational impacts (e.g., Khalaf et al., 2022 [10]; Deck and Jebaraj, 2015 [11]; Tuck, 2020 [12]).

2.2. Studies Using Input–Output Modeling in Net-Zero Transitions

Globally, I-O modeling has been employed to examine the economic implications of transitioning to net-zero emissions by 2050. In the United States, the Congressional Budget Office used I-O modeling to estimate the economic effects of carbon taxes [13]. Kay and Jolley (2023) applied I-O modeling to analyze the economic impact on various sectors if a USD 200/ton carbon tax were implemented to facilitate the net-zero transition [14]. They found that such a tax would lead to short-term price increases of 10–30% in carbon-intensive industries. Similarly, Fremstad and Paul (2019) used I-O modeling to assess the economic impact of a revenue-neutral carbon tax and its redistribution to benefit low-income households [15]. Rokicki et al. (2023) conducted a comparable study in Poland, comparing I-O modeling with computable general equilibrium (CGE) modeling to estimate the effect of the European Union's Emissions Trading System [16]. They found both models produced similar results, although I-O modeling potentially overestimated the impact of a carbon tax.

2.3. Studies on the Economic Impact of Renewable Energy

I-O modeling has also been used to assess the economic impacts of both traditional and renewable energy production. For example, Loomis (2015) used the JEDI I-O model to estimate the lifetime economic benefits of 23 wind farm projects in Illinois, finding that nearly 20,000 full-time equivalent jobs were created during construction [17]. Similar studies have used IMPLAN I-O modeling to estimate the impact of wind energy projects in states like Wyoming [10], North Dakota [18], and Minnesota [12].

In the context of solar power, Bae and Dall'erba (2016) used both the JEDI and IMPLAN I-O models to estimate the economic impact of a new solar power plant in Arizona. While they found similar employment estimates between the two models, there were differences in labor income estimates [19]. Loomis, Jo, and Aldeman (2016) also used the JEDI model to evaluate three different solar options for Illinois [20]. They observed significant variations in construction and operational impacts depending on the scale of operations and the presence of a local solar supply chain.

3. Data and Methods

The National Renewable Energy Laboratory (NREL) uses a benchmarking method to model the necessary costs incurred when installing a system using photovoltaic (PV) technology and monofacial monocrystalline silicon PV modules. The NREL-estimated construction costs are broken into three main categories: materials and equipment, labor, and other costs, including permitting fee, sale tax, contingency, interconnecting fee, and business overhead and profit. Their method accounts for all necessary system and project development costs at the national average. However, project pricing depends highly on region and project specifics such as local retail electricity rate structures, local rebate and incentive structures, competitive environment, and overall project or deal structures [21].

In this study, we asked developers of community solar projects who are familiar with the region to provide their expected construction costs using the same cost category from NREL. We averaged the responses from regional solar developers and obtained the expected construction costs for a 10 MW_{AC} project (Table 1). We then applied the conversion rate from NREL to obtain the average construction costs for a 5 MW_{AC} project and a 20 MW_{AC} project (Table 1). To protect proprietary information, we do not provide detailed categorical costs. However, our cost proportions are comparable to the costs provided by NREL. We also assume the average construction durations for a 5 MW_{AC} project, 10 MW_{AC} project, and 20 MW_{AC} project are six months, nine months, and twelve months, respectively.

Table 1. Expected total costs of construction.

Construction Phase Data Description	5 MW Project	10 MW Project	20 MW Project
Construction duration	6 months	9 months	12 months
Total construction phase employee compensation (USD)	2,665,000	5,330,000	10,660,000
Total construction materials and equipment cost (USD)	6,500,000	12,480,000	23,920,000
Permitting fees and taxes (USD)	1,040,000	1,560,000	2,340,000
Business overhead (USD)	2,080,000	3,380,000	5,460,000
Other costs (USD)	1,040,000	2,080,000	4,160,000
Total cost of construction (USD)	**13,325,000**	**24,830,000**	**46,540,000**
Land lease agreement (USD)	21,074	63,221	168,588
Total cost of construction and land lease agreement (USD)	**13,346,074**	**24,893,221**	**46,708,588**

On average, direct land use requirements for 1-axis tracking PV installations range from 4.2 to 10.6 acres/MW, with a capacity-weighted average of 6.3 acres/MW [22]. Therefore, a 5 MW project requires 31.5 acres, a 10 MW project requires 63 acres, and a 20 MW project requires 126 acres. The average annual leasing rate in Ohio is USD 1338 per acre (information provided by developers of community solar projects). The surveys from developers indicate no difference in the costs of leasing green fields and brownfields (distressed fields).

As of 2023, 268 companies in Ohio belonged to the photovoltaic supply chain [23]. Of those companies, 93 are photovoltaic-related manufacturers, producing goods from photovoltaic panels to silicon to installation systems [23]. Utility-grade installation of photovoltaics in Ohio has increased drastically, from less than 100 in 2022 to 1250 in 2023. According to the US Department of Energy, Ohio has two module manufacturers: First Solar and Illuminate USA [24]. First Solar produces 6300 MW_{DC}/yr of thin film, or cadmium telluride, panels. Illuminate USA started operations in February 2024 and plans to produce 5000 MW_{DC}/yr of crystalline silicon bifacial panels at full operational capacity.

Historically, Ohio has been a large producer of thin film panels. In 2023, Ohio reported the shipment of 1,176,948 solar panels [25]. However, these panels have mostly been exported rather than used within Ohio. In 2021, Ohio had over USD 170 million in exports of semiconductor devices and light-emitting diodes, which includes the solar panel commodity [26]. The thin film panels have a lower capacity and life span than their crystalline silicon counterparts, but they work better in cloudy, humid, and hot environments. Furthermore, crystalline silicon panels are the preferred panel for community solar developers in Ohio. Therefore, in the past, solar farm developers have chosen to import crystalline silicon panels rather than use the thin film panels produced in Ohio. With Illuminate USA joining the crystalline solar panel manufacturing industry in 2024, developers now have the opportunity to buy panels within Ohio.

To estimate the economic impact of the construction phase for different project sizes, we assume that 100% of crystalline silicon panels used in the programs are produced and purchased in Ohio. Other materials and equipment, such as mounting equipment and inverters, are not manufactured in Ohio but can be purchased locally at a 50% rate.

We assume that 80% of the labor is sourced from Ohio, as is required by USSEC to enter into Ohio's Payment in Lieu of Taxes (PILOT) agreement (Ohio General Assembly Reforms Renewable and Advanced Energy Tax Policy) [27] . We also assume the permitting fees and taxes are spent 100% in Ohio, and all other costs are spent in Ohio at the rate of 80%. All dollar values are expressed in 2023 dollars.

On average, a single solar project has a lifespan of 25 years. To measure the economic impacts of the operation and maintenance (O&M) phase, we averaged the expected operation and maintenance costs provided by developers. Our annual O&M cost estimate is roughly USD 13.1 per kilowatt (kW_{AC}). Of the estimated O&M expense, 60% goes toward labor and 40% of the estimate goes toward materials and equipment. It costs roughly USD 127,297 per year to operate a 5 MW_{AC} PV solar project, USD 254,594 to operate a 10 MW_{AC} project, and USD 509,188 to operate a 20 MW_{AC} project, including leasing costs (Table 2).

Table 2. Expected annual O&M costs for 5 MW_{AC}, 10 MW_{AC}, and 20 MW_{AC} projects.

Project Size	Labor Cost (USD)	Materials and Equipment (USD)	Land Lease Agreement (USD)	Total O&M Cost (USD)
5 MW	51,090	34,060	42,147	127,297
10 MW	102,180	68,120	84,294	254,594
20 MW	204,360	136,240	168,588	509,188

4. Results

4.1. Economic Impacts of a Single Project

As mentioned, we employ the JEDI model from NREL to estimate the economic impact of the construction phase for different project sizes. We assume that 100% of the crystalline silicon panels used in the programs are produced and purchased in Ohio. Other materials, such as mounting equipment and inverters, are not manufactured in Ohio but can be sourced locally for 50% of the required supply. Eighty percent of labor must be from Ohio, as is required for projects to enter Ohio's PILOT agreement. By utilizing the JEDI model with project-specific data inputs, assumptions, and regional economic information, we calculate each project's proportion of local spending (Table 3) and its overall economic impacts during the construction phase. The economic impacts of the operation phase are estimated using IMPLAN models.

This section presents the economic impacts of a single project of different sizes. Since it takes less than a year to build smaller projects, the jobs created in the construction phase are converted to full-time job years. For example, if two full-time construction workers are employed to construct a 5 MW_{AC} project for six months, we consider it one full-time job year.

The construction and operation of solar projects contribute to the economy through four channels:

- **Direct impact**: This impact measures the changes in manufacturing, construction, and O&M jobs directly associated with constructing and operating solar projects.
- **Indirect impact**: This impact measures the changes in employment, incomes, and sales in Ohio among vendors who supply intermediate goods and services to the construction and operation of solar projects.
- **Induced impact**: This impact measures the added local economic activities, such as purchasing entertainment, healthcare, retail, etc., led by the incomes generated through direct and indirect impacts.
- **Induced impact from land leasing**: The extra income from leasing land goes directly to households. Although this income does not generate direct employment, it will induce more local spending, thus, help support more jobs, and generate more income and sales in Ohio.

Table 3. Construction phase's local spending.

	Single 5 MW Project	Single 10 MW Project	Single 20 MW Project
Total direct construction cost (USD)	13,325,000	24,830,000	46,540,000
Local spending (USD)	8,853,000	16,562,000	31,304,000
Local spending as % of total construction	66.4%	66.7%	67.3%

Results from JEDI models.

4.1.1. Economic Impacts of a Single 5 MW_{AC} Project

It costs USD 13.25 million in Ohio to build a 5 MW_{AC} photovoltaics solar project. Of the total construction cost, 66.4% (USD 8.85 million) is expected to be captured in the state (Table 3). The construction of each 5 MW_{AC} project is expected to generate 23 direct job years and support another 30.9 full-time job years through indirect and induced effects. In addition, the income from land leasing helps to support another 0.15 job years through its induced effect. In total, the construction of a 5 MW_{AC} project supports about 54 Ohio full-time job years with total earnings of over 4.98 million dollars (Table 4). The construction of a 5 MW_{AC} photovoltaics solar project is expected to contribute USD 9.6 million to the state GSP and USD 16.9 million to the total state gross output (Table 4).

Table 5 summarizes the economic impacts of operating a 5 MW_{AC} project for a single year in Ohio. Collectively, the operation of a 5 MW project supports the equivalence of 0.97 full-time jobs through direct, indirect, and induced effects with an annual labor income of USD 94,252. The annual operation and maintenance expenses of a 5 MW project are expected to contribute USD 132,851 to the state GSP and USD 232,996 to the total state gross output.

A 5 MW_{AC} project is expected to support 78.22 full-time job years in Ohio with a total labor income of USD 8.9 million during its construction phase and 25 years of operation (Table 6). Throughout its lifetime, a 5 MW_{AC} project is estimated to contribute USD 12.9 million to the Ohio GSP and USD 22.7 million to the state's gross output (Table 6).

Table 4. The economic impacts of the construction of a 5 MW_{AC} project.

	Employment (Job Years)	Earnings (USD)	Value Added (USD)	Gross Output (USD)
1—Direct	23.0	2,985,400	3,470,000	4,212,200
2—Indirect	19.0	2,467,400	3,944,900	8,747,000
3—Induced	11.9	1,098,200	2,147,200	3,938,200
4—Induced impact from land leasing	0.15	8607	15,553	27,129
Total	54	6,559,607	9,577,653	16,924,529

Table 5. The economic impacts of operating a 5 MW_{AC} project for a single year.

	Employment (Job Years)	Earnings (USD)	Value Added (USD)	Gross Output (USD)
1—Direct	0.26	51,090	51,090	85,150
2—Indirect	0.10	8874	19,675	39,563
3—Induced	0.31	17,073	30,981	54,025
4—Induced impact from land leasing	0.30	17,215	31,105	54,258
Total	0.97	94,252	132,851	232,996

Table 6. The lifetime economic impacts of a 5 MW_{AC} project.

Phase	Employment (Job Years)	Earnings (USD)	Value Added (USD)	Gross Output (USD)
Construction	53.85	6,559,607	9,577,653	16,924,529
O&M	24.37	2,356,293	3,321,285	5,824,892
Total lifetime impact of a 5 MW project	78.22	8,915,900	12,898,938	22,749,421

4.1.2. Economic Impacts of a Single 10 MW_{AC} Project

It costs USD 24.83 million to build a 10 MW_{AC} solar project in Ohio. Of the total construction cost, 66.7% (USD 16.6 million) is expected to be captured in the state (Table 3). The construction of each 10 MW_{AC} project is expected to generate 65.6 direct job years and support another 85.6 full-time job years through indirect and induced effects. In addition, the income from land leasing helps to support another 0.46 job years through its induced effect. In total, the construction of a 10 MW_{AC} project supports about 151.66 Ohio full-time job years with total earnings of USD 12.3 million (Table 7). The construction of a 10 MW_{AC} photovoltaics solar project is expected to contribute USD 17.9 million to the state GSP and USD 31.7 million to the total state gross output (Table 7).

Table 8 summarizes the economic impacts of operating a 10 MW_{AC} project for a single year in Ohio. Collectively, the operation of a 10 MW_{AC} project supports the equivalence of 1.94 full-time jobs through direct, indirect, and induced effects with an annual labor income of USD 188,503. The annual operation and maintenance expenses of a 10 MW_{AC} project are expected to contribute USD 265,703 to the state GSP and USD 465,991 to the total state gross output.

A 10 MW_{AC} project is expected to support 200.14 full-time job years in Ohio with a total labor income of USD 17.1 million during its construction phase and 25 years of operation (Table 9). Throughout its lifetime, a 10 MW_{AC} solar project is estimated to contribute USD 24.5 million to the Ohio GSP and over USD 43.3 million to the state's gross output (Table 9).

Table 7. The economic impacts of the construction of a 10 MW_{AC} project.

	Employment (Job Years)	Earnings (USD)	Value Added (USD)	Gross Output (USD)
1—Direct	65.6	5,673,600	6,484,000	7,696,300
2—Indirect	52.9	4,627,900	7,400,000	16,685,500
3—Induced	32.7	2,019,200	3,948,000	7,241,100
4—Induced impact from land leasing	0.46	25,822	46,658	81,387
Total	151.66	12,346,522	17,878,658	31,704,287

Table 8. The economic impacts of operating a 10 MW_{AC} project for a single year.

	Employment (Job Years)	Earnings (USD)	Value Added (USD)	Gross Output (USD)
1—Direct	0.51	102,180	102,180	170,300
2—Indirect	0.20	17,748	39,350	79,126
3—Induced	0.62	34,146	61,962	108,050
4—Induced impact from land leasing	0.61	34,429	62,211	108,515
Total	1.94	188,503	265,703	465,991

Table 9. The lifetime economic impacts of a 10 MW_{AC} project.

Phase	Employment (Job Years)	Earnings (USD)	Value Added (USD)	Gross Output (USD)
Construction	151.66	12,346,522	17,878,658	31,704,287
O&M	48.48	4,712,585	6,642,570	11,649,782
Total lifetime impact of a 10 MW project	200.14	17,059,107	24,521,228	43,354,069

4.1.3. Economic Impacts of a Single 20 MW_{AC} Project

It costs USD 46.54 million to build a 20 MW_{AC} solar project in Ohio. Of the total construction cost, 67.3% (USD 31.3 million) is expected to be captured in the state (Table 3). The construction of each 20 MW_{AC} project is expected to generate 168 direct job years and support another 213.2 full-time job years through indirect and induced effects. In addition, the income from land leasing helps to support another 1.22 job years through its induced effect. In total, the construction of a 20 MW_{AC} project supports about 382.4 Ohio full-time job years with total earnings of USD 23.5 million (Table 10). The construction of a 20 MW_{AC} photovoltaics solar project is expected to contribute USD 33.7 million to the state GSP and over USD 60 million to the total state gross output (Table 10).

Table 11 summarizes the economic impacts of operating a 20 MW_{AC} project for a single year in Ohio. Collectively, the operation of a 20 MW_{AC} project supports the equivalence of 3.87 full-time jobs through direct, indirect, and induced effects with an annual labor income of USD 377,007. The annual operation and maintenance expenses of a 10 MW_{AC} project are expected to contribute USD 531,406 to the state GSP and USD 931,983 to the total state gross output.

A 20 MW_{AC} project is expected to support 479.13 full-time job years in Ohio with a total labor income of USD 32.9 million during its construction phase and 25 years of operation (Table 12). Throughout its lifetime, a 20 MW_{AC} solar project is estimated to contribute over USD 47 million to the Ohio GSP and USD 83.3 million to the state's gross output (Table 12).

Table 10. The economic impacts of the construction of a 20 MW_{AC} project.

	Employment (Job Years)	Earnings (USD)	Value Added (USD)	Gross Output (USD)
1—Direct	168.0	10,879,800	12,248,300	14,248,600
2—Indirect	132.1	8,765,600	14,015,400	32,069,100
3—Induced	81.1	3,757,500	7,346,700	13,474,600
4—Induced impact from land leasing	1.22	68,858	124,422	217,030
Total	382.4	23,471,758	33,734,822	60,009,330

Table 11. The economic impacts of operating a 20 MW_{AC} project for a single year.

	Employment (Job Years)	Earnings (USD)	Value Added (USD)	Gross Output (USD)
1—Direct	1.02	204,360	204,360	340,600
2—Indirect	0.40	35,496	78,700	158,253
3—Induced	1.23	68,293	123,924	216,099
4—Induced impact from land leasing	1.22	68,858	124,422	217,030
Total	3.87	377,007	531,406	931,983

Table 12. The lifetime economic impacts of a 20 MW_{AC} project.

Phase	Employment (Job Years)	Earnings (USD)	Value Added (USD)	Gross Output (USD)
Construction	382.42	23,471,758	33,734,822	60,009,330
O&M	96.72	9,425,170	13,285,139	23,299,565
Total lifetime impact of a 20 MW project	479.13	32,896,928	47,019,961	83,308,895

4.2. Lifetime Impacts of the Community Solar Program in Ohio

Since the true distribution of the size of facilities for each section of this program is unknown, we developed a potential rollout scenario of distribution, knowing that the community solar program in Ohio prioritizes smaller projects.

The 1000 MW_{AC} community solar program on various types of sites is a combination of 5 MW_{AC} and 10 MW_{AC} projects and will be allocated over four years. We assume thirty projects of 5 MW_{AC} and ten projects of 10 MW_{AC} will be built each year. The projects will be operated the year after construction and have a lifespan of 25 years. By the end of year 4, the construction of all projects will be completed (Table 13).

Table 13. Rollout scenario for 1000 MW_{AC} community solar program on various types of sites.

Year	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10 to Y24	Y25	Y26	Y27	Y28	Y29	Y30
Number of projects constructed																
5 MW	30	30	30	30												
10 MW	10	10	10	10												
Number of projects operated																
5 MW	0	30	60	90	120	120	120	120	120	120	120	120	90	60	30	0
10 MW	0	10	20	30	40	40	40	40	40	40	40	40	30	20	10	0

The 500 MW_{AC} on brownfields is the combination of 5 MW_{AC}, 10 MW_{AC}, and 20 MW_{AC} projects and will be allocated over four years. We assume seven projects of 5 MW_{AC}, five projects of 10 MW_{AC}, and two projects of 20 MW_{AC} will be built each year. The projects will be operated the year after construction and have a lifespan of 25 years. By the end of year 4, the construction of all projects will be completed (Table 14).

Table 14. Rollout scenario for 500 MW_{AC} community solar program on brownfields.

Year	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10 to Y24	Y25	Y26	Y27	Y28	Y29	Y30
Number of projects constructed																
5 MW	7	7	7	7												
10 MW	5	5	5	5												
20 MW	2	2	2	2												
Number of projects operated																
5 MW	0	7	14	21	28	28	28	28	28	28	28	28	21	14	7	0
10 MW	0	5	10	15	20	20	20	20	20	20	20	20	15	10	5	0
20 MW	0	2	4	6	8	8	8	8	8	8	8	8	6	4	2	0

The 250 MW_{AC} on qualifying Appalachian sites is the combination of 5 MW_{AC}, 10 MW_{AC}, and 20 MW_{AC} projects and will be allocated over two years. We assume seven projects of 5 MW_{AC}, five projects of 10 MW_{AC}, and two projects of 20 MW_{AC} will be built each year. The projects will be operated the year after construction and have a lifespan of 25 years. By the end of year 2, the construction of all projects will be completed (Table 15).

Table 15. Rollout scenario for 250 MW_{AC} community solar program on the Appalachian region's distressed sites.

Year	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10 to Y24	Y25	Y26	Y27	Y28	Y29	Y30
Number of projects constructed																
5 MW	7	7														
10 MW	5	5														
20 MW	2	2														
Number of projects operated																
5 MW	0	7	14	14	14	14	14	14	14	14	14	14	7	0		
10 MW	0	5	10	10	10	10	10	10	10	10	10	10	5	0		
20 MW	0	2	4	4	4	4	4	4	4	4	4	4	2	0		

Table 16 summarizes the impacts of our hypothetical rollout scenario for each project and the total impact of the entire Ohio Community Solar Pilot Program. The 1000 MW_{AC} project on various types of sites with a project cap of 10 MW_{AC} is expected to support an average of 17,392 Ohio job years and contribute roughly USD 2.5 billion to GSP. The 500 MW_{AC} project on brownfields with a project cap of 20 MW_{AC} is expected to support an average of 10,026 Ohio job years and contribute about USD 1.2 billion to GSP. The 250 MW_{AC} project in Appalachian Ohio is expected to support an average of 5013 Ohio job years and contribute USD 613.9 million to GSP. The entire Ohio Community Solar Pilot Program, which combines the three projects, is expected to support 32,430 Ohio job years with total earnings of USD 3.03 billion and contribute USD 4.37 billion to GSP and USD 7.72 billion to gross output.

Table 16. Expected economic impacts of the Ohio Community Solar Pilot Programs.

Program	Employment (Job Years)	Earnings (USD)	Value Added (USD)	Gross Output (USD)
1000 MW on various types of site	17,392	1,752,272,274	2,528,721,662	4,464,093,255
500 MW on brownfields	10,026	854,002,766	1,227,754,510	2,170,536,328
250 MW in Appalachian Ohio	5013	427,001,383	613,877,255	1,085,268,164
Total	32,430	3,033,276,423	4,370,353,426	7,719,897,747

4.3. Tax Impacts

Ohio Revised Code (R.C.) § 5727.75 exempts "qualified energy projects", including renewable energy generation, from tangible personal property tax. If a solar project in Ohio meets certain criteria as certified by the director of the Ohio Department of Development, it utilizes the real and personal property tax abatement and payment in lieu of taxes (PILOT) framework (Ohio Revised Code (R.C.) § 5727.75 *exemption on tangible personal property and real property of certain qualified energy projects*. Retrieved from https://codes.ohio.gov/ohio-revised-code/section-5727.75, accessed on 8 August 2024).

To qualify for the exemption, the owner or lessee pursuant must submit an application to the power sitting board for a certificate before 31 December 2024. Construction must begin on or later than 1 January 2009, and before 1 January 2025. For projects greater than 20 MW, the local county commissioners must approve the exemption by resolution within 30 days or else have declared it an "alternative energy zone". The PILOT is distributed in the same manner as the tangible personal property tax (to localities and school districts).

The owner or a lessee pursuant of a qualified solar project shall make annual service payments of USD 7000 per megawatt of nameplate capacity in lieu of taxes to the county treasurer. However, 5727.75(E)(1)(b) permits the county to impose an annual service payment to be made in addition to the PILOT. The sum of the additional service payment and the PILOT payment shall not exceed USD 9000 per megawatt of nameplate capacity located in the county.

Given the above, we calculated the potential tax revenues paid to counties using the lower bound of USD 7000 per megawatt and the upper bound of USD 9000 per megawatt. The entire Ohio Community Solar Pilot Program (1750 MW_{AC} of new capacity) is expected to bring USD 12.25 million to USD 15.75 million in annual tax revenue to the counties (Table 17). Throughout its lifetime, The Ohio Community Solar Pilot Program is expected to bring between USD 318.5 million and USD 409.5 million in tax revenue to counties in Ohio (Table 18). A significant portion of this tax revenue will go to fund Ohio's schools and the remainder will be distributed among all other local governments in the state.

Table 17. Potential annual tax revenues from the Ohio Community Solar Pilot Program.

Program	Minimum Tax Revenue (USD)	Maximum Tax Revenue (USD)
1000 MW_{AC} on various types of site	7,000,000	9,000,000
500 MW_{AC} on brownfields	3,500,000	4,500,000
250 MW_{AC} in Appalachian Ohio	1,750,000	2,250,000
Total	12,250,000	15,750,000

Table 18. Potential lifetime tax revenues from the Ohio Community Solar Pilot Program.

Program	Minimum Tax Revenue (USD)	Maximum Tax Revenue (USD)
1000 MW_{AC} on various types of site	182,000,000	234,000,000
500 MW_{AC} on brownfields	91,000,000	117,000,000
250 MW_{AC} in Appalachian Ohio	45,500,000	58,500,000
Total	318,500,000	409,500,000

5. Sensitivity Analysis

In this section, we present an alternative economic impact analysis based on the assumption that no crystalline solar panels are manufactured in Ohio, and that all solar panels used in community solar projects are imported from outside the state. This sensitivity analysis aims to evaluate the difference in economic impacts of the projects where panels are sourced from outside locations and demonstrate the importance of the local supply chain.

In this analysis, we assume that 100% of the solar panels are produced outside of Ohio. Local developers can procure 50% of the necessary supplies from local retailers, while the remaining 50% can be purchased from out-of-state vendors. Currently, the JEDI model for solar farm construction distinguishes only between materials produced in-state and those sourced from out-of-state. It does not account for whether the materials required for solar farms are purchased domestically or internationally. In addition, outsourcing solar panels does not affect the economic impacts of the operating phase.

Table 19 illustrates the proportion of in-state spending under the scenario where 100% of solar panels are sourced from outside the state. When solar panels are outsourced, an average of 40% of the construction costs is spent in Ohio. In contrast, when panels are produced locally, in-state spending increases to 67% (Table 3).

Table 19. Construction phase's local spending (100% of panels outsourced).

	Single 5 MW Project	Single 10 MW Project	Single 20 MW Project
Total direct construction cost (USD)	13,325,000	24,830,000	46,540,000
Local spending (USD)	5,668,000	10,192,000	18,564,000
Local spending as % of total construction	42.5%	41%	39.88%

Results from JEDI models.

Tables 20–22 present the economic impacts associated with the construction of solar projects with capacities of 5 MW, 10 MW, and 20 MW, respectively, under the assumption that all solar panels are sourced from outside Ohio. Overall, when solar panels are outsourced, the direct impacts of the construction phase remain constant, while the indirect and induced impacts are significantly smaller compared to the scenario where the panels are produced locally.

For instance, the construction of a single 10 MW project supports 52.9 full-time job years through indirect impact and an additional 32.7 full-time job years through induced impact when the panels are produced by local manufacturers (Table 7). In contrast, when all panels are outsourced, the construction of the same 10 MW project supports only 30.75 full-time job years through its indirect impacts and an additional 22.05 full-time job years through its induced impacts (Table 21).

Table 20. The economic impacts of the construction of a 5 MW_{AC} project (100% of panels outsourced).

	Employment (Job Years)	Earnings (USD)	GSP (USD)	Gross Output (USD)
1—Direct	23	2,985,400	3,470,000	4,212,200
2—Indirect	11.65	1,222,100	2,068,700	3,760,600
3—Induced	8.30	769,500	1,504,400	2,759,100
4—Induced impact from land leasing	0.15	8607	15,553	27,129
Total	43.10	4,985,607	7,058,653	10,759,029

Table 21. The economic impacts of the construction of a 10 MW_{AC} project (100% of panels outsourced).

	Employment (Job Years)	Earnings (USD)	GSP (USD)	Gross Output (USD)
1—Direct	65.63	5,673,600	6,484,000	7,696,300
2—Indirect	30.75	2,137,200	3,647,800	6,712,600
3—Induced	22.05	1,361,800	2,662,400	4,882,800
4—Induced impact from land leasing	0.46	25,822	46,658	81,387
Total	118.88	9,198,422	12,840,858	19,373,087

Table 22. The economic impacts of the construction of a 20 MW_{AC} project (100% of panels outsourced).

	Employment (Job Years)	Earnings (USD)	GSP (USD)	Gross Output (USD)
1—Direct	168.00	10,879,800	12,248,300	14,248,600
2—Indirect	73.10	3,784,300	6,510,900	12,123,300
3—Induced	52.70	2,442,700	4,775,500	8,758,000
4—Induced impact from land leasing	1.22	68,858	124,422	217,030
Total	295.02	17,175,658	23,659,122	35,346,930

6. Discussion

The IMPLAN and JEDI models are designed for short-term (annual) impact analysis rather than long-term projections. The models rely on a static economic structure (input–output table) for a specific year [28–31]. To estimate the long-term economic impact of operating solar projects, we must assume a static economy structure, which means the Ohio economy (relationships between industries, technology, production processes, etc.) is assumed not to undergo any dramatic change in the future for the results to hold. In reality, economic changes such as shifts in employment patterns, productivity, and industrial growth will occur, especially for a dynamic industry such as renewable energy [32–35]. For example, no energy technologies have changed as dramatically as photovoltaics, with costs dropping by almost 100 times since the 1950s [36]. Thus, extending economic impact results in the long term without accounting for likely structural changes and changes in energy policies can limit the long-term accuracy of the results.

However, most solar projects' economic impact occurs during the construction phase, which is expected to last less than five years. Hence, the construction phase's impacts are expected to be more immediate and less susceptible to long-term economic shifts; we believe our method is well suited to estimate the economic impacts of the community solar program in Ohio.

The second limitation of this study is that we rely on regional developers for construction and O&M costs. While the data provide more reliable and accurate estimates for Ohio, they cannot be generalized to other states as labor and material costs vary across regions.

Our study was limited to assessing the economic impact of solar construction and operations in Ohio, yet the broader academic literature points to additional benefits and challenges that are beyond the scope of our study. However, these are worth acknowledging as part of the broader policy discussions associated with energy transition. As Carley and Konisky (2020) acknowledge in their research on clean energy transition, the transition to alternative energy sources has the potential to "perpetuate pre-existing sets of winners and losers" ([37], p. 569). Additional work on energy transition by Raimi, Carley, and Konisky (2022) finds that Appalachian communities are among those communities with increased vulnerability and subject to the greater impacts [38]. Appalachian Ohio communities have already experienced significant economic, fiscal, and workforce impacts due to the closure of coal-fired power plants [39].

Jolley et al. (2019) found that the economic impacts of coal-fired power plant closures had a ripple effect into neighboring counties, yet fiscal effects of power plant closures were more centralized to the county where power plants were located due to Ohio's policy that utilities pay tangible personal property tax [39]. Expanding these findings to our study suggests that the fiscal effects of utility-grade solar facilities would centralize fiscal benefits such as property taxes in the communities where the solar facilities are located. Recent work by Hao and Michaud (2024) examined the effect of utility-grade solar on property values in the Midwest. They found a 0.5–2.0% increase in property values near utility-grade solar projects [40]. Additionally, they found that smaller solar projects (less than 20 MW) yielded a more positive impact on property values. Utility-grade solar could provide a boom in property taxes for communities where utilities did not previously exist but accelerate the fiscal losses for coal facilities as they cease to produce power in other communities.

Construction of new utility-grade solar will impact land use patterns as well. Recent work by Maguire et al. (2024) found that 70% of solar farms in rural areas were sited on agricultural land [41]. Ohio has a strong history of agriculture; a 2015 study found that Ohio ranks 7th in soybean production, 8th in corn production, 2nd in egg production, 8th in hog and pig production, and 11th in milk production among the 50 states [42] The cumulative economic impact of utility-grade solar would certainly diminish if in-use agricultural land was taken out of productivity and converted to solar farms. Likewise, placing solar farms on marginal lands would add value to lands currently unused or underused. Milbradt et al (2014) found that 11% of the land in the continental United States is considered marginal (abandoned cropland, barren lands, abandoned mine lands, etc.) [43], including 28,935 km^2 in Ohio. Unfortunately, the authors found these marginal lands were only suitable to produce 2.2 GW of solar power in Ohio. The opportunity costs of land use are important considerations beyond the scope of our study.

7. Conclusions

Throughout their lifetimes, a single 5 MW_{AC} project is expected to support 78.22 job years and contribute USD 12.9 million to GSP (Table 6), a single 10 MW_{AC} project is expected to support over 200 job years and contribute USD 24.5 million to GSP (Table 9), and a single 20 MW_{AC} project is expected to support 479.13 job years and contribute over USD 47 million to GSP (Table 12).

Since the true distribution of the size of facilities for each section of this program is still being determined, we only presented the impacts of a hypothetical rollout scenario, with the knowledge that there will be more smaller projects of 5 MW_{AC} than bigger projects of 10 MW_{AC} and 20 MW_{AC}. Our hypothetical rollout scenario shows that Ohio's Community Solar Pilot could support 32,430 job years and contribute over USD 4.37 billion to the state's GSP (Table 16) and USD 409.5 million in local tax revenue over its lifetime (Table 18). If the program ends up with a different combination of large and small projects, the total lifetime economic impacts of the program can be calculated using the lifetime impacts of single projects: Tables 6, 9 and 12.

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