What Will Drive Agrivoltaics Adoption: Evidence from the US Solar Developer's Survey

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Abstract

The rapid expansion of solar energy on US farmland faces land-use conflicts and community opposition. Agrivoltaics is proposed as a middle-ground solution, but which factors will influence a solar developer's decision to adopt agrivoltaics remain under-explored. We examined factors that will influence a developer's decision to adopt agrivoltaics as well as the current status and future interests in agrivoltaics development in the US. Our findings show that reducing community opposition to large scale solar energy projects is the strongest driver of agrivoltaics adoption, carrying more than a 25% weight in their decisions. At the same time, developers face challenges such as coordination difficulties, a lack of regulatory assurances, and perceived risks associated with novel dual-use technology. Despite such challenges, we found that solar developers are building several agrivoltaics projects across the country and are interested in developing more in the future. Addressing barriers related to limited policy incentives, regulatory uncertainty, coordination challenges, and perceived risks will be critical to accelerating agrivoltaics development in the US.

Keywords: Community Opposition, Solar in Farmland, SWOT-AHP, Solar Developers, Novel Technology Risk

1. Introduction

Solar energy is a domestic, low-emissions energy resource with significant potential to support long-term energy supply, energy security, and grid reliability. It can significantly reduce the environmental footprint of global energy consumption while supporting long-term global sustainability goals through 2050 [1]. The US has expanded solar energy capacity at a faster rate than any other energy source as part of broader efforts to reduce the environmental impacts of energy production [2] Achieving this scale of deployment has land-use implications, with solar development projected to require between four and eleven million acres across the contiguous US [3].

To achieve this ambitious goal, large utility scale photovoltaic solar energy projects are being developed in rural farmlands in the US [4]. Farmland is particularly suitable for large scale solar energy development because it combines high solar potential with accessible locations, proximity to the electric grid, favorable slopes and environmental conditions, and the availability of large contiguous tracts for utility scale projects [5]. About 93% of solar energy projects are being developed in rural US out of which 70% are installed on farmland [6]. In New York State, for instance, about 44% of existing utility-scale solar projects are developed on agricultural land, and around 84% of the suitable land for solar development is agricultural land, including about 35% of active farmland in one of its counties [7]. About 80% of new solar projects built in US are excepted to be on farmland by 2040 [8]. About 1.1% to 2.4% of the US cropland will be converted to photovoltaics to meet solar energy targets by 2050 [9], corresponding to approximately 4.2 to 9.2 million acres of cropland, based on total US cropland reported in the 2022 Census of Agriculture [10]. The expansion of solar energy projects at this scale with such an enormous land requirement causes community opposition which is a major challenge for solar developers to build solar energy projects across the US [11, 12].

A study tracking opposition for renewable energy across the US found that, in 2024, 459 counties or municipalities across 44 states imposed restrictions on renewable energy siting—16% more than in 2023 [13]. Opposition groups raised enough voice to influence decision-making process delaying or canceling solar energy projects in Michigan [14]. In western and northern New York, about 42% of the resident opposed large utility scale solar installation in the communities [15]. A nationwide survey of solar developers found that about 60% of the solar projects are delayed by at least six months and about 40% of the projects are canceled in the last five years [16]. The cost per successful project is significantly higher than the average cost spent per project due to project cancellations [17]. The unrecoverable average sunk cost per solar project is about $2 million per project and the average lost due to project delay is about $30,000 per megawatt [16]. A recent advancement in solar energy technological development opens a possibility of co-locating solar energy system with agricultural crops, also called as agrivoltaics [18].

The purpose of this study is to understand solar developer's motivations and barriers for agrivoltaics adoption in the US. More specifically, we examine the current state of agrivoltaics development from the perspective of solar developers in the US, developer's future interest in adopting agrivoltaics, and the key motivations and barriers influencing technology adoption decisions. Solar developers spend large amount of time, money, and effort to gain community support to develop solar projects [11]. Understanding developer's current development activities, future interests, and perceived drivers and constraints can inform the design of targeted incentives, help reduce adoption barriers, and improve the overall acceptance of agrivoltaics projects among solar developers. Greater acceptance of agrivoltaics among developers may, in turn, lower investment costs associated with community opposition to large scale solar projects and accelerate the deployment of agrivoltaics in the US.

We surveyed solar developer across the US to understand their motivation and barriers of agrivoltaics adoption. We used strengths, weaknesses, opportunities, and threats analytical hierarchical process (SWOT-AHP) to understand positive and negative aspects of agrivoltaics adoption. This is a multi-criteria decision analysis approach which commonly used in strategic management [19] by structuring and solving problems that involves multiple criteria such as strengths, weaknesses, opportunities, and threats [20, 21]. This method is useful in solving a problem where multiple solutions appear to be equally important and thus, differentiation of items based on public opinion is essential to prioritize multiple solutions. SWOT-AHP has wider application in various fields such as growth of the renewable energy sector

[22], natural resource management [23], and sustainable waste management [24].

SWOT-AHP is appropriate for emerging technologies like agrivoltaics where developer's perceptions plays a critical role in shaping early adoption trajectories but data availability remains limited due to early phase of technological innovation and the confidentiality of project-level information [25]. This method provides sufficiently structured yet relatively flexible approach to quantify and prioritize relative importance of identified factors, enabling consistent, evidence-based decision-making [26]. The SWOT-AHP approach effectively captured solar developer's macro-level motivations and barriers to agrivoltaics adoption in the US, providing valuable insights for strategic planning and policy interventions to support agrivoltaics development.

Agrivoltaics is advocated as a solution to overcoming community opposition to large scale solar [27, 28]. This is a novel technology that co-locates solar energy with agricultural enterprises such as crops, livestock, and pollinators, providing an alternative solution to standalone solar energy projects. It is relatively more favored by farmers [29], public, and government officials [30, 31] compared to standalone solar projects. Agrivoltaics increases land-use efficiency and diversifies farm-revenue stream while providing access to quality land for solar energy projects [29, 32]. However, a benefit-cost assessment of agrivoltaics project suggests that it requires a significant amount of incentives and policy support to make it as profitable as standalone solar [33]. More importantly, agrivoltaics needs a far more complicated technological shift, larger capital investment cost, and significantly more land compared to standalone solar to facilitate agricultural operations [34].

Solar developers play a crucial role in advancing agrivoltaics technology. Their technical knowledge and experience of developing standalone solar can be valuable in the development of agrivoltaic projects. However, the understanding of developer's motivations and barriers to adopt agrivoltaics is very limited. So far, only a few studies have explored developers perspective on agrivoltaics adoption [30, 31]. These studies are also confined to local or regional level providing a limited understanding of developer's insight on agrivoltaics adoption at the national level. A lack of understanding of their motivation and barriers may hinder technology adoption, diffusion, and expansion, thus, weakening potential of agrivoltaics to contribute towards achieving the electrification goal. Understanding developer's motivation and barrier for agrivoltaics adoption is essential to overcome agrivoltaics adoption barriers, balance agrivoltaics profitability with community interests, and align policy incentives with sustainability goals to meet net-zero emission target. The lack of such understanding often result into disengagement of solar developers in the technology development process [35].

This paper contributes to the growing literature on agrivoltaics adoption by studying motivations and barriers influencing solar developer's decision to adopt agrivoltaics system across the US. These motivations and barriers were identified through the series of focus group discussions among developers across the US and synthesized to key sixteen determinants of agrivoltaics adoption at the current early stage of technological advancement. These factors were, then, adapted into SWOT-AHP survey framework to study their relative importance. Our results indicate that the opportunity to reduce community opposition for large scale solar is the biggest factor for solar developers to adopt agrivoltaics. Other factors are related to energy policy, project management, technology risks, and finances. We further quantified the influence of each factor in the adoption decisions. We found that community opposition alone accounts for more than one-fourth of the overall decision-making process related to the technology adoption. Finally, we discuss how these factors vary by energy scale, agricultural enterprise type, and regional energy market characteristics [36].

In addition, we captured current state of agrivoltaics development in the US using close ended single and multiple-choice questions. We further studied solar developer's future interest in adopting agrivoltaics technology. We found that a large majority of solar developers are currently developing medium to large scale agrivoltaics projects mostly with livestock and pollinator habitat. About 60% solar developers are interested in developing 5MW or above sized agrivoltaics. We further found that about 59% of solar developers are interested in developing agrivoltaics with livestock and specialty crops.

The rest of the paper is organized as follows: section 2 outlines focus group discussions and defines the SWOT factors followed by the methods in section 3. The method section includes survey design, data collection, SWOT-AHP process, and empirical framework. Section 4 presents results describing demographics of solar developers, current and future of agrivoltaics development trends, and motivations and barriers of agrivoltaics adoption using SWOT-AHP. The motivations and barriers are discussed based on the full sample as well as grouping them by solar energy scales, number of energy markets, and agricultural enterprises. Finally, section 5 discusses study findings and policy implications and section 6 concludes the study.

2. Focus Group Discussions and SWOTs of Agrivoltaics

In this section, we briefly discuss focus group discussions and identification process of SWOT factors, followed by the definition and a brief discussion of these factors (Table 1). These factors were presented to solar developers for pairwise comparisons in the survey. For the purpose of this study, we consider these factors as motivators or barriers of agrivoltaics for solar developers to adopt agrivoltaic projects in the US.

Table 1 (Table with SWOT Factors) Here

2.1. Focus Group Discussions

We conducted six focus group discussions with solar developers, each session having a unique combination of participants, averaging five developers per discussion. The first discussion was held on the third quarter of 2022 with twelve developers. We explored their perspectives on the current status of agrivoltaic projects development and willingness to adopt the technology.

We, then, conduced one focus group discussion with six farmers in the same quarter of 2022. Following the insight from two discussion sessions, we designed a behavioral experiment-based discrete choice model (DCE) survey to assess developer's willingness to adopt agrivoltaics. The survey instrument was then pilot-tested in the second focus group discussion with solar developers.

Based on feedback from subsequent discussions, we adopted SWOT-AHP framework instead of DCE, as the DCE was less well suited to the current context of agrivoltaics research for three key reasons. First, agrivoltaics adoption is shaped by a wide range of economic, social, and regulatory considerations that are difficult to represent comprehensively within a DCE framework. Second, confidentiality considerations surrounding cost information posed a limitation on revealing monetary values through DCE. Third, the hypothetical nature of DCE scenarios, combined with the early stage of agrivoltaics development, constrained respondent's ability to reliably evaluate and compare DCE alternatives.

SWOT-AHP integrates qualitative insights with quantitative pairwise comparisons, enabling developers to systematically prioritize strengths, weaknesses, opportunities, and threats. This approach provides a feasible and structured method for establishing a baseline understanding of solar developers' motivations and challenges in adopting agrivoltaics at the early stage of its development [25]. From the researcher's perspective, this method allows us to capture subtle differences and complexities in developer's decision making which are directly applicable for informing policy interventions. Thus, we identified several motivating and limiting factors of agrivoltaics and distilled down to sixteen factors that external and internal to agrivoltaics which either motivates or restricts its adoption among developers. Finally, we formalized sixteen factors into strengths, weaknesses, opportunities, and threats (SWOTs) developing a SWOT-AHP framework to study developer's motivation and barriers of agrivoltaics adoption.

2.2. Strengths of Agrivoltaics

Strengths are positive characteristics internal to agrivoltaics that motivates solar developers to adopt agrivoltaics. Strengths of agrivoltaics for a solar developers include: a strong commercial drive, a dual revenue stream, community support and acceptance of solar, and appealing aesthetics compared to standalone solar. The strong commercial appeal of agrivoltaics arises from cost savings due to lower sunk costs, ease of permitting and regulatory processes [31], as well as easier access to land with high solar potential that is well connected to the electric grid [5]. Agrivoltaics generates dual revenue stream from crops and solar energy production without negatively affecting land productivity [37]. Past research has reported that solar receives more support from community if it is integrated with agricultural production [27]. Finally, Agrivoltaics is perceived as a more aesthetically pleasing form of solar technology than conventional solar projects [27] because of its natural integration of plants in the system design.

2.3. *Weaknesses of Agrivoltaics*

Weaknesses are negative characteristics internal to agrivoltaics that discourages solar developers to adopt agrivoltaics. Weaknesses of agrivoltaics include: requiring more land than standalone solar, limited adoption, coordination difficulty and higher risk and liability. Though agrivoltaics is a potential proposed solution for land competition between food and energy production, it requires more land than conventional solar energy projects due to the inter-panel spacing to accommodate crops and cultural operations [38]. Consolidating land parcels to secure sufficiently large tracts for utility scale agrivoltaics poses a significant challenge for solar developers due to distributed land ownership, variable land valuation, complex decision-making processes, community opposition, and concerns over farmland preservation and land restoration. These issues arise coordination difficulties between developers and farmers/landowners [39, 31]. Another challenges of agrivoltaics is higher risk and safety liabilities during project development, operation, and management because of frequent agricultural activities in the agrivoltaics site [31, 30]. Finally, the adoption of agrivoltaics technology is very limited among solar developers resulting in lack of experience and limited data availability, especially at its current early development stage. This leads to higher capital investment costs [39]. The limited data availability on system performance further makes investment decision complicated for solar developers [39, 30].

2.4. Opportunities of Agrivoltaics

Opportunities are positive characteristics external to agrivoltaics that motivate solar developers to adopt the technology. Major opportunities associated with agrivoltaics adoption are: expanding solar into rural farmlands, reducing vegetation management and operational costs, reducing community opposition to solar, and gaining reputation as a agrivoltaics leader. The broader acceptance of agrivoltaics among agricultural communities [39, 31] presents a strategic opportunity for solar developers to expand solar development on farmland through agrivoltaics adoption. Adopting agrivoltaics early potentially establish solar developers as agrivoltaics leaders, which puts them in competitive advantage position in the solar business [39, 30]. Another appealing aspect of agrivoltaics is reducing vegetation management and operational costs by replacing unnecessary vegetation with agricultural enterprises such as crops, livestock, and pollinators, which is an additional external benefit beyond the food and energy production goal of agrivoltaics [39, 40].

2.5. Threats of Agrivoltaics

Threats are negative characteristics external to agrivoltaics that discourages solar developers to adopt agrivoltaics, such as lack of external investment funds, commercial risks associated with novel technology, lack of regulatory assurance to support agrivoltaics, and lack of policy incentive. [31] reported that solar developers were concerned about financial burden and challenge to identify investors for agrivoltaics compared to standalone solar. Commercial risks arise because agrivoltaics challenges the standardized, low-risk business model that underpins utility scale solar development. The absence of long-term performance data, unclear risk allocation across stakeholders, and higher upfront capital costs [41] increase perceived risks, limiting adoption despite its potential social and land-use benefits. The investment in agrivoltaics technology is further limited by the lack of regulatory support and policy incentives [39, 29]. In many instances, agrivoltaics is opposed at local to national levels and policies are less supportive towards agrivoltaics development [13, 42]. Furthermore, existing policies, such as tax credits, are primarily designed to incentivize standalone solar projects and are not yet sufficiently tailored to promote agrivoltaics adoption [42, 43]. The uncertainty around long term support of incentives and policies [44], restrictive land-use policy, zoning regulations, ambiguity in defining agrivoltaics further limits agrivoltaics development [43, 45].

3. Method

3.1. Survey Design and Data Collection

We designed a solar developer survey with three distinct sections. The first section provided brief background information about agrivoltaics, and specified agrivoltaics system configuration. Particularly, we specified agrivoltaics in the survey as solar panels mounted on 6-12 ft. tall metallic poles with 18-42 ft. row spacing and were co-located with crops for energy and food production. Then we described the context of the survey, and requested developers to thoughtfully answers survey questions. The second section collected information on respondents' experience with traditional solar and agrivoltaic projects, followed by questions assessing their interest in pursuing agrivoltaics development in the future. In the third section, we provided an example demonstration SWOT pairwise comparison process (Figure 1) and asked respondents to follow the same process to compare SWOT factors within strengths, weaknesses, opportunities, and threats categories. Finally, we asked respondents to make pairwise comparisons of overall strength, weakness, opportunity, and threat at the end of the survey. We followed this approach to reduce survey fatigue and lower response rate in the second set (Appendix B). The SWOT factors represented motivations and barriers of agrivoltaics for solar stakeholder to adopt the technology in the US.

Figure 1 (SWOT Factor Comparison Example) Here.

We disseminated online and paper versions of the survey from July to December 2024. The online version of the survey was emailed to solar developers using solar stakeholder database jointly developed by Sustainably Colocating Agricultural and Photovoltaic Electricity Systems (SCAPES) project, solar industry partners, and solar stakeholder working groups. For the survey dissemination we collected information such as company type, program affiliations, websites, email, vendor IDs, and phone numbers from 213 solar company websites. We removed duplicate information which resulted in

179 unique and verified email IDs and updated contact information. The final consolidated database from all sources resulted into a list of 250 solar developers across the country. We followed up twice via email reminding solar developers to fill out the survey. We also disseminated the online survey to solar developers through solar industry partner organizations such as Solar and Storage Industries Institute (SI2), Solar Energy Industries Association (SEIA), and American Solar Grazing Association (ASGA). We further distributed paper-printed version of the survey at two agrivoltaics specific conferences (Solar Farm Summit and World Agrivoltaics Conference) and one solar energy industry trade show (RE+).

We reached out to 300 solar developers through online and paper surveys and received 100 completed surveys resulting into 33% response rate. Pairwise deletion approach was employed to handle missing data during SWOT analysis resulting into 47% sample size retention rate. Our sample size is comparable with past studies adopting SWOT-AHP framework in their study [23]. Past research has reported challenge in receiving responses from solar developers for survey studies [39]. SWOT-AHP is a tool that can accommodate small sample size when SWOT factors are carefully selected in the presence of industry practitioners, professionals, and experts.

3.2. SWOT-AHP Process

SWOT-AHP is a two-step process of identifying SWOT factors and deriving scale of priorities (or weights) of the factors. The joint SWOT-AHP process overcomes limitations of qualitative nature of SWOT by assigning quantitative weight and ranking factors [46]. Weights indicate relative importance of ranked factors in the decision-making process based on respondent's subjective judgment. The first step of identifying SWOT factors is described in the focus group discussion section. In the second step, we generated a set of six pairwise combinations of factors within each category to compare their relative importance (Figure 1). Then, we asked solar developers to make pairwise comparisons on a scale of 1 to 9. If the pair received 1, both factors in the pair are equally important. The factor receiving 3 to 9 in the pairwise comparison set is 3 to 9 times more important than the second factor [26] indicated by the green lines with outward pointed arrow and the text description above it (Figure 1). This process was repeated for strengths, weaknesses, opportunities, and threats. At the end, we asked developers to make a pairwise comparison among strengths, weaknesses, opportunities, and threats (Appendix B).

3.3. Empirical Framework

Let $\mathbf{W} = (a_{ij})$ be an $n \times n$ positive reciprocal pairwise comparison matrix with properties

$$a_{ij} = \frac{w_i}{w_j}, \quad a_{ii} = 1, \quad a_{ji} = \frac{1}{a_{ij}}, \quad \forall i, j \in \{1, \ldots, n\},\ i \neq j, \quad n = 4, \tag{1}$$

where i and j index the SWOT factors being compared.

$$\mathbf{W} = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \frac{w_1}{w_3} & \frac{w_1}{w_4} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \frac{w_2}{w_3} & \frac{w_2}{w_4} \\ \frac{w_3}{w_1} & \frac{w_3}{w_2} & \frac{w_3}{w_3} & \frac{w_3}{w_4} \\ \frac{w_4}{w_1} & \frac{w_4}{w_2} & \frac{w_4}{w_3} & \frac{w_4}{w_4} \end{bmatrix} \quad \mathbf{w} = \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ w_4 \end{bmatrix} \tag{2}$$

The matrix $\mathbf{W}$ measures how strongly one SWOT factor is preferred over another, based on the judgments of solar developers. Intuitively, w_i represents the relative importance of factor i, and $a_{ij} = w_i/w_j$ indicates how many times more important factor i is compared to factor j. In the perfectly consistent case[1], the pairwise comparisons satisfy $a_{ij} = w_i/w_j$. In empirical applications, however, $\mathbf{W}$ is constructed from judgment data and may deviate from this exact ratio. In this case, the priority vector $\mathbf{w}$ is derived from $\mathbf{W}$ by computing the principal eigenvector and normalizing it so that $\sum_{i=1}^{n} w_i = 1$ [46].

Assuming $\mathbf{W}$ is positive and $\mathbf{w} > 0$, a perfectly consistent comparison matrix satisfies

$$\mathbf{W}\mathbf{w} = n\mathbf{w}. \tag{3}$$

The underlying priority of each factor is captured by the vector

$$\mathbf{w} = (w_1, w_2, w_3, w_4)^\top, \tag{4}$$

[1] A perfectly consistent case is one in which all pairwise judgments align exactly with one another, so that the implied importance ratios follow transitive logic through the corresponding multiplied ratios. The perfectly consistent comparison matrix yields a principal eigenvalue equal to n.

where $w_i > 0$ is the priority weight of factor i, $\mathbf{w}$ is the normalized principal eigenvector of $\mathbf{W}$.

The principal eigenvalue of $\mathbf{W}$, denoted $\lambda_{\max}$, satisfies:

$$\mathbf{W}\mathbf{w} = \lambda_{\max}\mathbf{w}, \quad w_i = \frac{v_i}{\sum_{k=1}^{4} v_k}, \tag{5}$$

with v_i being the i^{th} component of the principal eigenvector. This normalization converts the weights into relative proportions, allowing for clear interpretation and comparison of the importance of each factor across categories.

The eigenvalues, λ, are solutions to

$$\det(\mathbf{W} - \lambda\mathbf{I}) = 0, \tag{6}$$

where $\mathbf{I}$ is the $n \times n$ identity matrix.

Matrix $\mathbf{W}$ is perfectly consistent if and only if $\lambda_{\max} = n$; deviations of $\lambda_{\max}$ from n indicate inconsistency. Inconsistency measures the extent to which a solar developer's pairwise comparisons violate the proportional logic of a perfectly consistent judgment.

The Consistency Index (CI), the measure of how much developer's pairwise comparisons deviate from perfect logical consistency, is defined as

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1}. \tag{7}$$

The Consistency Ratio (CR) evaluates whether the inconsistency is acceptable:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}, \tag{8}$$

where RI is the average consistency index of a randomly generated reciprocal matrix of order n. CR < 0.10 indicates an acceptable level of consistency. For $n = 4$, RI $= 0.89$ [46].

Local or factor priorities (within-category weights) are calculated separately for each SWOT category such that the sum of factor weights within each category equals one. Let $w_{i|C}$ denote the local priority of factor i, called as local/factor priority, in SWOT category C. Then, for each category:

$$\sum_{i \in C} w_{i|C} = 1, \quad \forall\, C \in \{\text{S, W, O, T}\}, \tag{9}$$

where S = Strengths, W = Weaknesses, O = Opportunities, and T = Threats.

Global priorities are obtained by multiplying local priorities by the weight of their parent category, denoted W_C. The global priority (overall weight) of factor i is therefore:

$$w_i^{\text{global}} = W_C \cdot w_{i|C}, \quad i \in C. \tag{10}$$

The sum of all global priorities across all sixteen SWOT factors satisfies:

$$\sum_{C \in \{\text{S, W, O, T}\}} \sum_{i \in C} w_i^{\text{global}} = 1. \tag{11}$$

All AHP-derived priorities are non-negative. For interpretation in the agrivoltaics adoption context, global priorities associated with Weaknesses and Threats are assigned a negative sign to reflect their adverse influence, while Strengths and Opportunities retain positive signs.

$$w_i^{\text{global}} = \begin{cases} > 0, & \text{for Strengths and Opportunities,} \\ < 0, & \text{for Weaknesses and Threats.} \end{cases} \tag{12}$$

4. Results

4.1. Demographics of Solar developers

All solar developers who participated in the study reported that their company has operated in the US in the last five years. Our study represents solar developers operating throughout the US, and at varied stages of business development from new solar developers entering into the US energy market, to established solar developers actively operating in the regional to national energy markets. About 93% of solar developers reported that their company has operated photovoltaic solar projects in the US. The remaining 7% are currently developing new photovoltaic solar projects in the US. Many of our participants operated in more than one [36] designated electric power markets in the last five years (Figure 2). The top four energy markets in which our respondents operated in the last five years were Mid-continent (MISO, 64%), PJM interconnection (PJM, 61%), New York (NYISO, 45%), and Southeast (SE, 43%). Among survey respondents, 31% of developers operated in a single U.S. energy market, while 14% operated in two markets, 15% in three markets, 13% in four to five markets, and 27% in six or more markets.

Figure 2 (Distribution map of developers) Here

We asked solar developers to indicate all the scale categories of photovoltaic solar project that their solar company typically develops among following four energy scale categories: 20+MW (large utility), 5MW to 20MW (small utility), 100KW to 5MW (medium), and below 100KW (small). About 43% of solar developers develop large utility scale, 38% develop small utility scale, 60% develop medium scale, and 15% develop small scale photovoltaic solar energy projects. About 65% of the developers developed photovoltaic solar energy projects within a single category of energy scales whereas 15% solar developers develop energy projects in two, 18% in three, and 2% in four solar energy scale categories mentioned above. In response to the question regarding developer's departmental affiliation within their solar companies, 22% of respondents reported working in engineering, procurement, and construction, followed by marketing (20%), corporate management (17%), finance (5%), and project management (2%). About 34% indicated their affiliation with other departments in their solar company.

4.2. Current and Future of Agrivoltaics Development Trends

Survey responses show that a large majority of solar developers are currently developing medium scale to large utility scale agrivoltaic projects (Table 2). About 96% of the solar developers expressed interest in developing

100KW or larger agrivoltaic projects in the next five years, out of which majority of the developers are interested in developing 5MW or larger agrivoltaic projects.

Table 2 (Current status and future interests in agrivoltaics adoption) Here.

Regarding the type of agrivoltaics projects, we found that solar develops have developed more than one type of agrivoltaics. About 59% of solar developers are developing agrivoltaics with livestock, 49% with pollinator habitat, 30% with specialty crops, 25% with row crops, and 14% with other crops. About 14% of our respondents are not developing any agrivoltaics projects. Further, we found that about 29% solar developers mentioned that their company is interested in developing agrivoltaics with livestock, 25% with specialty crops, 21% with row crops, 16% with pollinator habitat, and 6% with other crops within the five years. However, about 3% developers mentioned that their solar company is not interest in developing agrivoltaics projects in the US in the same period.

Figure 3 (Currently Developing agrivoltaics projects in the US) Here.

Combining energy scale and agricultural enterprise types from the total reported agrivoltaic projects in the survey, the largest share of projects currently being developed in the US are medium scale (100 kW to 5 MW) projects with livestock (52%) and pollinator habitat (40%). (Figure: 3). About 32% and 34% of solar developers are developing large utility scale

(20+MW) agrivoltaic projects with livestock and pollinator habitat, respectively. Similarly, about 32% and 30% developers are building medium scale agrivoltaics with specialty crops and small scale (Below 100 KW) agrivoltaics with livestock respectively.

Overall, the results indicate that agrivoltaics deployment in the US is already oriented toward medium to large utility scale projects. Solar developers are showing strong interest in further scaling up their agrivoltaics projects over the next five years. Agrivoltaics with livestock and pollinator dominate current and near-future development of agrivoltaics compared to crop based agrivoltaics.

4.3. SWOT-AHP: Motivations and Barriers of Agrivoltaics Adoption

Motivations and barriers for the adoption of agrivoltaics by solar developers were summarized based on the full sample, solar energy scale (Table A.3 and Figure 4), US energy markets (Table A.4 and Figures 5), and agricultural enterprises (Table A.5 and Figure 6). In addition to the full sample, classifying SWOTs by energy scale, energy markets, and agricultural enterprises allows us to capture the heterogeneous motivations and barriers faced by different types of solar developers under diverse farming contexts across all US energy markets. This disaggregation ensures that strategic priorities and policies are tailored based on the need of developers prioritizing specific energy scale, energy markets, and agricultural enterprises for agrivoltaics development. Solar developers were grouped into respective energy scale and crop enterprise categories based on current status of agrivoltaics development by their solar company.

The factor receiving the highest weight in factor and global priorities within each SWOT category are bolded in each of the three summary tables. The consistency ratio (CR) values for all SWOT categories in the summary tables were less than 0.10, indicating that the results across all categories are within the acceptable threshold of the consistency index [46]. The highest factor priority weight represents the most important factor within each SWOT category. The highest global priority weight represents the most important factor among all SWOT factors.

4.3.1. SWOT Priorities for the Full Sample

The factor priority and global priority weights of SWOT factors based on the full sample are reported in the first column under factor and global priorities respectively in the table A.3[2] and global priorities are visualized as grey lines spider web plots in figure 4[3]. Our analysis showed that solar developers considered the opportunities presented by agrivoltaics to be the most important factor, assigning them an average priority weight of 34%. This was followed by threats (28%), strengths (23%), and weaknesses (15%),

[2]Factor and global priorities for full sample are reported in Tables A.3, A.4, and A.5 to compare results between the full sample and respective categories. Full sample results in all three tables are identical.

[3]Global priorities for full sample are also visualized in Figures 4, 5, and 6 to compare results between the full sample and respective categories. Full sample results in all three figures are identical.

indicating that developers are most focused on potential benefits and external challenges when evaluating agrivoltaics adoption. The smallest priority weight received by weaknesses suggests that the benefits of agrivoltaics outweighs the its limitations in solar developers decision to adopt agrivoltaics. Strengthening external opportunities and addressing concerns about external threats are crucial in motivating solar developers to adopt agrivoltaics.

Considering all SWOT factors based on global priority weight for the full sample, reducing community opposition for solar (opportunity, 15%) is the biggest motivating factor for solar developers to adopt agrivoltaics. The community support for agrivoltaics (strengths, 11%) and lack of policy incentives (threat, 11%) are positive and negative factors which ranked as the second equally most important motivator and barrier for agrivoltaics adoption. Similarly, higher risk and liability (weakness, 7%) and reducing operational cost (opportunity, 7%) are two equally important SWOT factor ranked in the third position that affect solar stakeholder's agrivoltaics adoption decision.

4.3.2. SWOT Priorities Based on Solar Energy Scale

The influence of SWOT factors on the decision of solar developers to adopt agrivoltaics varies with the energy scale of agrivoltaics. Comparing global priorities of SWOT factors across all the project scales, we found that the opportunity to reduce community opposition for solar energy projects remains as the most important factor influencing developer's agrivoltaics adoption decision (Table A.3 and Figure 4). For large utility scale and medium scale developers, the weights are 19% and 23% respectively and that for small utility and small scale developers is equal (24%). Coordination difficulty, a weakness, and the opportunity to reduce operational cost were ranked as the second most important factors influencing agrivoltaics decision by large utility scale (11%) and small utility scale (12%) solar developers. Medium and small scale solar developers mentioned coordination difficulty (weakness, 13%) and reducing operational cost (opportunity, 18%) as the second most important factors in their respective decisions to adopt agrivoltaics technology.

Figure: 4 (Energy Scale Spider Plot) Here

For large utility scale developers, community support (strength, 7%), limited agrivoltaics adoption (weakness, 7%), and expanding solar into farmland (opportunity, 7%) remained as the third most but equally important factors affecting agrivoltaics adoption decision (Table A.3 and Figure 4). Small utility scale developers viewed gaining reputation as an agrivoltaics leader (opportunity, 7%) and the lack of regulatory assurances (threat, 7%) as the third most important factors influencing their decision on agrivoltaics adoption. Medium and small scale solar developers identified reducing operational cost (opportunity, 12%) and coordination difficulty (weakness, 15%), respectively, as the third most important factors influencing their agrivoltaics adoption decision.

4.3.3. SWOT Priorities Based on Energy Markets

We estimated priority for solar developers by grouping them into the number of regions they are operating in the US (Table A.4 and Figure 5). They were grouped in four categories: single, 2-3, 4-5, and 6+ energy markets. Opportunity to reduce community opposition for solar energy ranked as the top priority for solar developers to adopt agrivoltaics regardless of number of energy markets they are operating in. This result shows that community opposition to solar is a major barrier for solar energy project development across the country. The priority weights for the factor vary based on the number of regions operated, suggesting that impact of community opposition on decision making of solar developers varies with the with the energy markets. The smallest weight for the community opposition on decision making is 18% among developers operating in 2-3 regions. This weight is, however, larger than the weight assigned to the factor by the full sample of solar developers. The findings suggest that locally operating developers may be better positioned to navigate community concerns. This highlights an opportunity to leverage agrivoltaics as a socially acceptable pathway for solar deployment in regions with limited prior exposure to large-scale solar projects.

Figure: 5 (Energy Market Spider Plot) Here

The priority weight of opportunity to reduce community opposition to solar is 0.26 (26%) for developers operating in four or more energy markets (Table A.4) suggesting that more than one fourth of their decision to adopt agrivoltaics is influenced by the opportunity to reduce community opposition to solar. These solar developers consider community opposition as relatively more important factor in their decision to adopt agrivoltaics as compared to those operating in three or less regions. This suggests that the national-level developers place greater emphasis on reducing community opposition for solar in their agrivoltaics adoption decision compared to developers operating in local or regional markets.

Opportunity to reduce operational cost ranked in the second position for all solar developers. Coordination difficulty also remains as the third most important factor influencing the decision to adopt agrivoltaics for all solar developers except those operating in 4-5 energy markets. Even though the weight of each factor varies with the number of energy markets, the weight of above factors ranking in second and third positions are close to each other suggesting that their impacts on solar developer's decision to adopt agrivoltaics is about the same. Compared to top two highly ranked factors, the third most important factor affecting the decision to adopt agrivoltaics varies more widely across four categories of energy markets.

Solar developer's third most important factors influencing agrivoltaics adoption vary by number of energy markets. Developers operating in a single region emphasized gaining a reputation as agrivoltaics leaders (opportunity, 8%) and lack of regulatory assurance (threat, 8%). In contrast, developers operating in 2–3 and 4–5 energy markets identified limited adoption (weakness, 10%) and coordination difficulty (weakness, 11%), respectively, as their third most important factors. For developers operating in 6+ energy markets, expanding solar into farmland (opportunity, 7%) and community support for agrivoltaics (strength, 7%) were equally important.

These patterns suggest that single-region developers are more concerned with reputation-building and regulatory clarity, which can help reduce community opposition and create a more level playing field [47]. In contrast, developers operating across multiple regions appear more focused on scaling up agrivoltaics deployment, emphasizing coordination, land access, and community support to enable larger-scale project development.

4.3.4. SWOT Priorities Based on Agricultural Enterprises

We further classified SWOT priorities based on agricultural enterprises (Table A.5 and Figure 6). Opportunity to reduce community opposition to solar energy projects remains the most important factor influencing solar developer's decision to adopt agrivoltaics. The weights range from 23% to 27% depending upon agricultural enterprises suggesting about one fourth of the effort on decision making is devoted to the effort to reduce community opposition for solar energy projects. The second most important factors for solar developers operating agrivoltaics with row crops, specialty crops, and livestock are the opportunity to reduce operational cost and barriers due to coordination difficulty with landowners/farmers. For solar developers operating agrivoltaics with pollinator habitat, reducing operational cost is the second most important factor affecting the decision to adopt agrivoltaics.

Figure: 6 (Ag Enterprise Spider Plot) Here

Several factors ranked as the third most important factors influencing solar developer's decision to adopt agrivoltaics, which also vary with the agricultural enterprise types. Solar developers with row crop agrivoltaics indicated that limited agrivoltaics adoption (weakness, 6%), gaining a reputation as agrivoltaics leader (opportunity, 6%) and lack of regulatory assurances for agrivoltaics (threat, 6%) are the three equally important factors affecting their decision to adopt agrivoltaics. For solar developers operating agrivoltaics with specialty crops, the third most important factors are lack of regulatory assurances (threat, 7%) and gaining reputation as agrivoltaics leader (opportunity, 7%). However, solar developers operating agrivoltaics with livestock stated that the community support for agrivoltaics (strength, 7%), converting solar into farmland (opportunity, 7%), gaining reputation as agrivoltaics leader (opportunity, 7%), and lack of regulatory assurance (threat, 7%) as four equally important factors ranked in third place affecting their agrivoltaics adoption decision. For solar developers with pollinator habitat, coordination difficulty (weakness, 11%) was the third most important factor affecting their decision to adopt agrivoltaics.

5. Discussion and Policy Implication

This study evaluated relative importance of sixteen motivations and barriers to agrivoltaics adoption among solar developers in the US. We explored these factors from multiple dimensions based on solar energy scale, US solar energy markets, and types of agricultural enterprises using SWOT-AHP approach. We found that decision to adopt agrivoltaics is highly influenced by the external factor such opportunities and threats compared to internal factors such as strengths and weaknesses. The opportunity to reduce community opposition emerge as the most important factors accounting for about 25% weight in solar developer's decision to adopt agrivoltaics regardless solar energy scale, number of energy markets, or agricultural enterprise types. This suggests that the lack of social acceptance for solar is a significant binding constraints on solar development than financial or technical challenges.

Agrivoltaics can be an pathway to reduce community opposition for large scale solar because it is generally perceived as a more acceptable form of solar energy projects than standalone solar [27, 47]. For solar developers, community opposition has been one of the major cost drivers of solar energy projects [15, 27]. A survey of utility scale solar developers found that at least 30% of the solar energy projects were canceled and about 60% were significantly delayed in the US and the community opposition is among the top three reasons for the cancellation or the delay [16]. To overcome such social backlashes, solar developers are adopting various strategies such as meetings, workshops, community engagement, and adjustment to project design [11]. However, addressing local environmental and livelihood concerns such as losing farmland to solar [35] may require strategic planning and implementation throughout the energy project initiation and development cycle. Agrivoltaics co-locates solar with local agricultural enterprises with minimal disruption to the local agricultural land, farmer's livelihood, and environment which could be a more acceptable solution while simultaneously expanding solar in farmland. Agrivoltaics, by its nature, has flexibility to address such concerns about standalone solar. Thus, agrivoltaics could potentially be a viable pathway to promote utility scale solar energy expansion while simultaneously addressing community concerns about standalone solar project and mutually benefiting solar developers, farmers, and the community.

Besides, several other factors have relatively small but impactful in the solar developer's decision to adopt agrivoltaics. Such positive factors are opportunity to expand solar into farmland, gaining reputation as agrivoltaics leader in the community, and community support for agrivoltaics. While the first benefit is naturally embedded with system configuration of agrivoltaics, solar developers continuous effort to address local community, livelihood, and farmland preservation concerns through agrivoltaics adoption would potentially establish them as an agrivoltaics leader in the community [31, 30]. Similarly, relatively small but negatively impacting in solar developer's decision to adopt agrivoltaics are lack of policy incentives, and lack of regulatory assurances, risk and liability associated with novelty of technology. For example, Massachusetts agrivoltaics policy is considered as an example because of its clearly defined solar sitting standard in farmland but, the policy is also criticized as inadequate due to its non-mandatory and continuously changing guidelines [45]. Such conflicting provisions in policies can limit scaling opportunities and create mixed outcomes for agrivoltaics development [45, 48]. The continuously changing priorities of governments at various levels on renewable energy technologies including agrivoltaics creates a long-term commitment vacuum adding uncertainty in adoption, research, technology advancement, and policy formulation [13]. Bringing such clarity in the policy, regulation, and long-term commitments are crucial in advancing agrivoltaics development in the US [45, 43].

The rest of the factors remain as less influential than those discussed above in solar developer's decision to adopt agrivoltaics. Nonetheless, these factors should receive attention in the policy formulation processes for several reasons. First, these factors emerged from intensive multiple rounds of focus group discussions with solar developers and farmers across the US, indicating that these are among the crucial factors influencing agrivoltaics development in the US. Second, these factors have frequently emerged in several literature on agrivoltaics adoption as important factors affecting agrivoltaics development. For example, strengths such as strong commercial drive, dual revenue stream, and appealing aesthetics appear to be less influential in our study. However, solar developers and farmers value these mutual benefits arising from the increased land productivity and dual revenue stream [29, 31]. This mutual arrangement provides access to high quality rural farmland for solar developers and generates stable long-term revenue income as risk management strategy against crop failure and farm revenue decline for farmers.

Solar developers play a pivotal role in scaling up agrivoltaics. This study offers a macro-level economic assessment of the factors shaping developer's adoption decisions and strategically prioritizes the key motivators and barriers influencing the decision. The findings identify pathway for policy interventions needed in both the short and long run to accelerate agrivoltaics deployment and identify need for public policies that enhance its benefits while addressing constraints that limit developer participation. Disaggregated results by energy scale, agricultural enterprise type, and market participation reveal substantial heterogeneity in developer responses, underscoring the need for targeted policy instruments rather than one-size-fits-all approaches.

While community opposition consistently emerges as the most influential factor affecting agrivoltaics adoption, the relative importance of other factors varies widely across the full sample and subgroup categories. This variation highlights pronounced heterogeneity in developer's priorities and the impacts of secondary adoption drivers. Understanding the sources of this heterogeneity lies beyond the scope of this study and represents an important direction for future research. Ultimately, the effectiveness of policies, targeted incentives, and agrivoltaics support programs will depend on efforts to account for this heterogeneity, reduce adoption barriers, and strengthen key motivators that facilitate solar developer's adoption of agrivoltaics technologies.

6. Conclusion

This study analyzed the key motivators and challenges influencing agrivoltaics adoption among US solar developers, the current and future perspective of agrivoltaics development. We found that solar developers are motivated by opportunities associated with agrivoltaics development, particularly the potential to reduce community opposition to large scale solar projects and, in some cases, reduce operational costs. However, external factors beyond developer's control—-such as coordination difficulties with farmers and landowners, lack of policy incentives, and the absence of clear regulatory frameworks—-remain major challenges limiting agrivoltaics adoption. Despite these constraints, medium scale to large utility scale agrivoltaics projects are currently under development in the US, with several projects integrating solar energy with livestock grazing and pollinator habitat. Solar developers further express strong interest in pursuing utility scale agrivoltaics projects within the next five years. From an energy policy perspective, these findings highlight the importance of addressing existing barriers through targeted policy support, financial incentives, clear regulatory frameworks, and local ordinances that facilitate coordination between developers and farmers or landowners. Such policy interventions are essential to reduce uncertainty, improve project feasibility, and accelerate agrivoltaics deployment while advancing national electrification goals through expanded solar energy development.

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Tables

Table 1: Factors identified in each SWOT category.

Strengths (S)	**Weaknesses (W)**
S1: Strong commercial drive for agrivoltaics	**W1:** Agrivoltaics require more land than solar alone
S2: Dual revenue stream from solar and agriculture	**W2:** Limited adoption of agrivoltaics by other solar developers
S3: Community support and acceptance of solar with agrivoltaics	**W3:** Difficulty of coordinating operations with farmers/landowners
S4: Appealing aesthetics of agrivoltaics compared to solar alone	**W4:** Higher risk and liability during project development, operation, and management
Opportunities (O)	**Threats (T)**
O1: Expanding solar into rural farmlands	**T1:** Lack of investment funds for agrivoltaics (e.g., loan, microfinance)
O2: Reducing vegetation management and operational cost	**T2:** Commercial risk associated with novel technology
O3: Reducing community opposition to solar	**T3:** Lack of regulatory assurances to support agrivoltaics
O4: Gaining reputation as agrivoltaics leader	**T4:** Lack of policy incentives for agrivoltaics (e.g., tax credits)

Notes: SWOT = Strengths, Weaknesses, Opportunities, and Threats. We conducted several focus group discussions with solar developers from 2022 and 2024. Strengths and Opportunities are internal and external positive factors of agrivoltaics that motivates solar developers to adopt agrivoltaics. Weaknesses and Threats are internal and external negative factors of agrivoltaics that demotivates solar developers to adopt agrivoltaics.

Table 2: Current and future interest in agrivoltaics project development by energy scale categories.

Energy Scale	Currently Developing	In the Next 5 Years
Large Utility Scale (20+ MW)	40%	37%
Small Utility Scale (5 MW—20 MW)	33%	26%
Medium Scale (100 KW—5 MW)	52%	34%
Small Scale (Below 100 KW)	14%	2%
None	-	2%
Total Sample (N)	63	62

Notes: One solar developer selected more than one energy scales. So, the sum of percentage for the "Currently Developing" column is more than 100%. Values were rounded to the nearest whole number.

Figures

<u>Please read the following example and instructions carefully. Later, we will ask you to make similar pairwise comparisons.</u>

We would like you to compare the relative importance of factors pairwise (e.g., "A vs. B" and "B vs. C" in the table below). If both factors are equally important, put an X under 1. If the factor on the left is more important, put an X in one of the boxes on the left of 1. If the factor on the right is more important, put an X in one of the boxes on the right of 1.

<table>
<tr><td colspan="5">The importance of the factor on the left side increases relative to the factor on the right as the scale moves to the left from 3 to 9</td><td>1 = Both are equally important</td><td colspan="5">The importance of the factor on the right side increases relative to the factor on the left as the scale moves to the right from 3 to 9</td></tr>
<tr><td colspan="11">1 = Both are equally important, 3 = Somewhat more important, 5 = Much more important, 7 = Extremely more important, 9 = Absolutely more important</td></tr>
<tr><td></td><td>9</td><td>7</td><td>5</td><td>3</td><td>1</td><td>3</td><td>5</td><td>7</td><td>9</td><td></td></tr>
<tr><td>A</td><td>X</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>B</td></tr>
<tr><td>B</td><td></td><td></td><td></td><td></td><td></td><td>X</td><td></td><td></td><td></td><td>C</td></tr>
</table>

Figure 1: SWOT Example presented to solar stakeholder before asking to make a pairwise comparison.

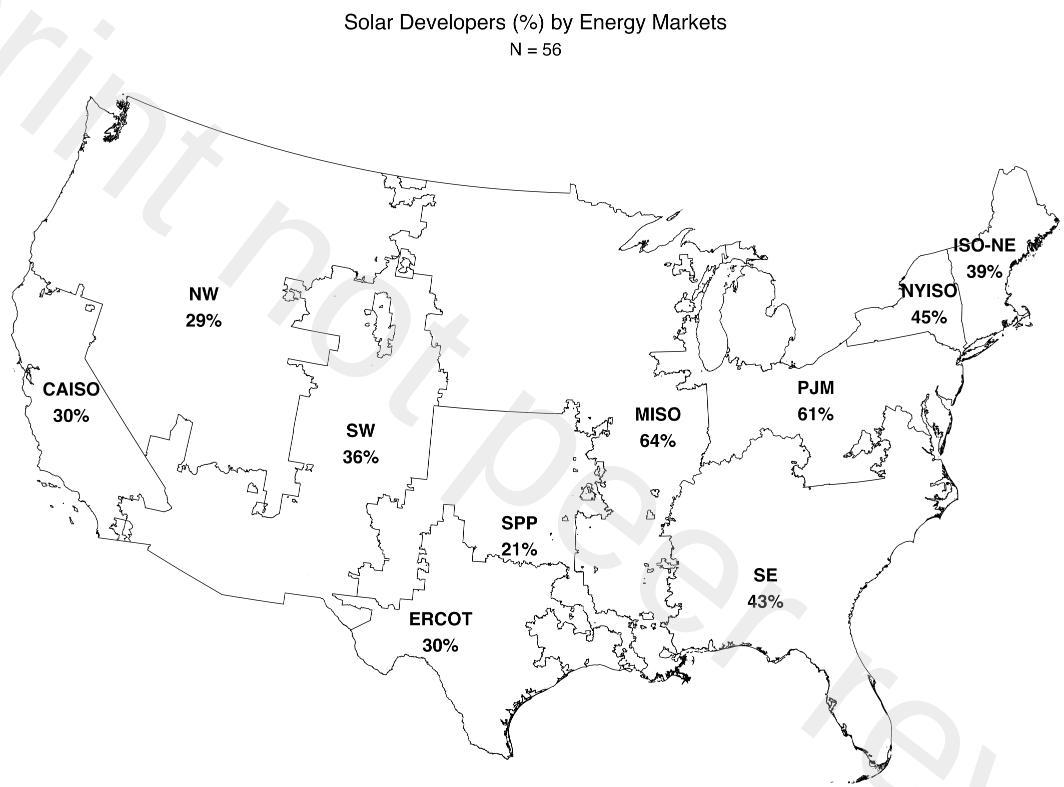


Figure 2: Geographical Distribution of solar developers

Notes: This map shows regional distribution of our survey participant's solar company operating over the last five years. A single solar developer is operating in more than one energy markets which is why the sum of percentages is more than 100%. CAISO = California, NW = Northwest, SW = Southwest, ERCOT = Texas, SPP = Southwest Power Pool, MISO = Mid-continent, SE = South east, PJM = PJM Inter-connection, NYISO = New York, ISO-NE = New England.

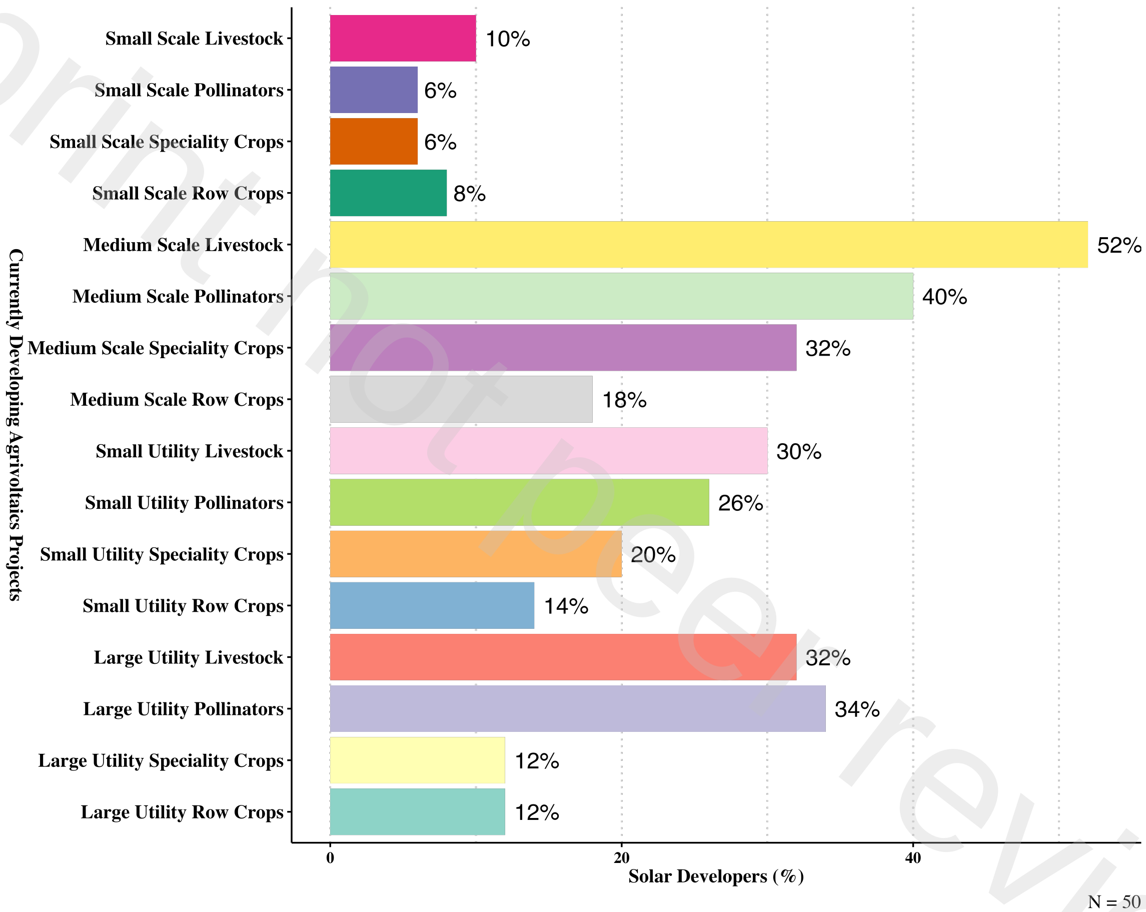
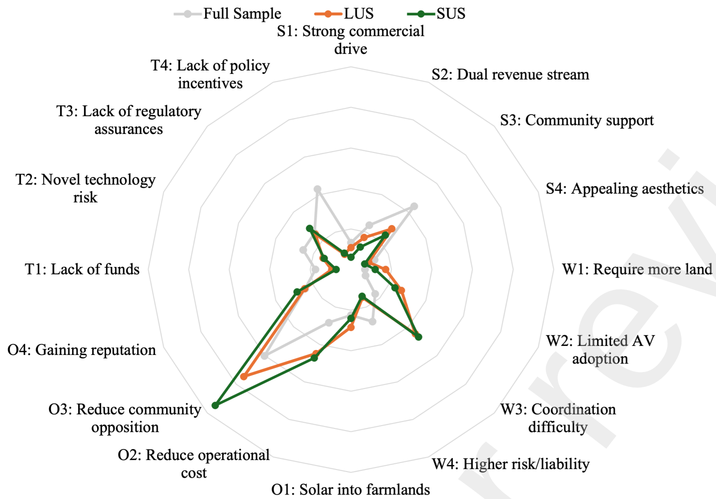
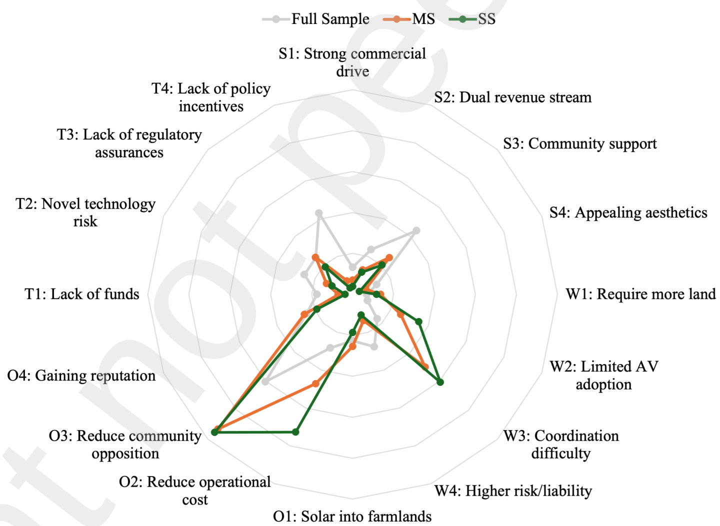


Figure 3: Currently developing agrivoltaics projects in the US.

Notes: Percentages are rounded to the nearest whole number. The sum of percentage is more than 100% because single developers selected more than one option. This chart was developed by cross-tabbing two questions from the survey that provides information about currently developing agrivoltaics projects by energy scale (Appendix B, question 1) and agricultural enterprise (Appendix B, question 2) types.



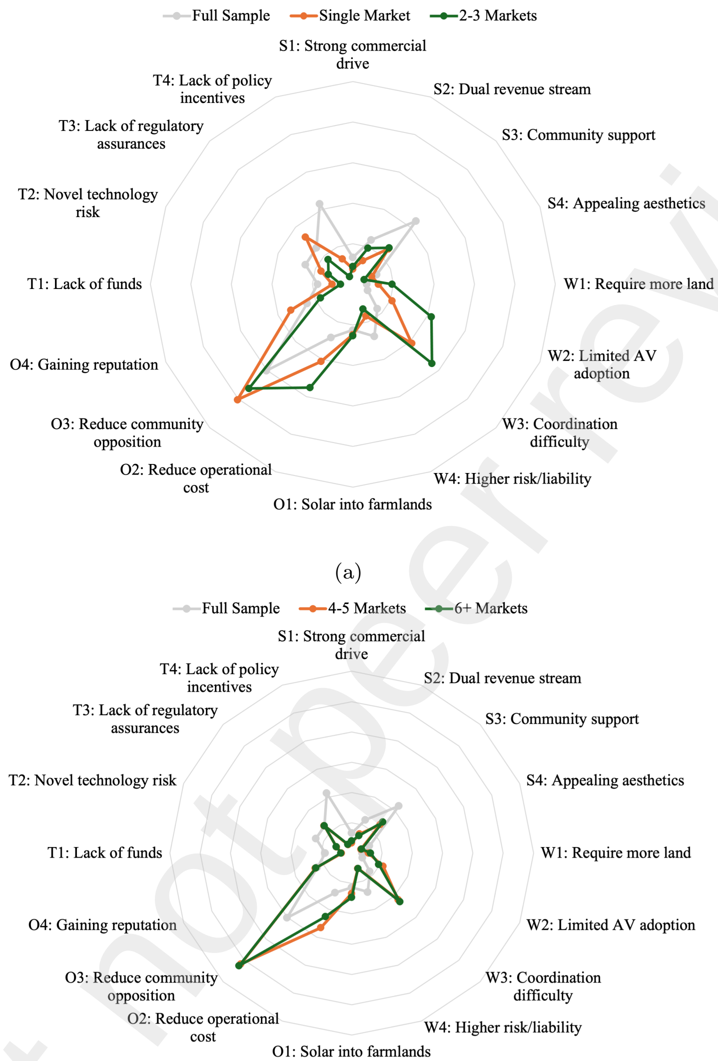
(a)



(b)

Figure 4: Comparative distribution of SWOT factor's global priorities by solar energy scales and the full sample.

Notes: The spider chart illustrates differences in weighting patterns across the full sample (Full Sample), large utility scale (LUS), small utility scale (SUS), medium scale (MS), and small scale (SS) solar developers, with colors distinguishing each group. For each factor, greater radial distance from the center denotes a higher weight and, therefore, greater importance in the agrivoltaics adoption decision.

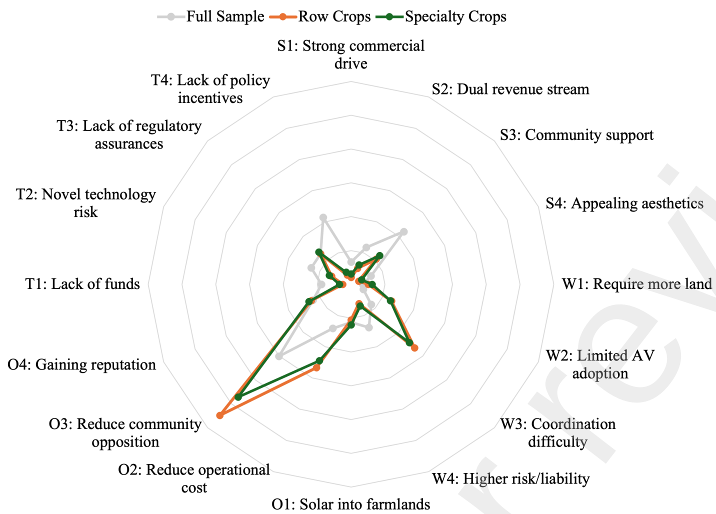


(a)

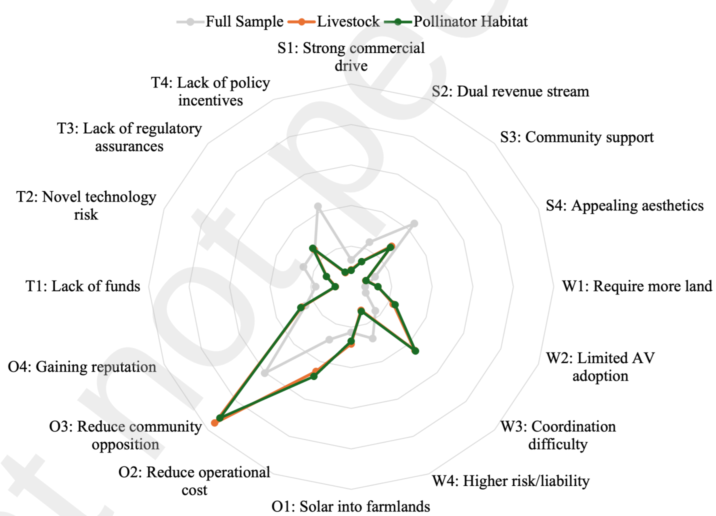
(b)

Figure 5: Comparative distribution of SWOT factor's global priorities by US energy markets and the full sample.

Notes: The spider chart illustrates differences in weighting patterns across full sample of solar developers and developers operating in single market, 2-3 energy markets, 4-5 energy markets, and 6+ energy markets across the US. For each factor, greater radial distance from the center denotes a higher weight and, therefore, greater importance in the solar developer's agrivoltaics adoption decision.



(a)



(b)

Figure 6: Comparative distribution of SWOT factor's global priorities by agricultural enterprises and the full sample.

Notes: The spider chart illustrates differences in weighting patterns across the full sample (Full Sample) and various agricultural enterprises such as row crops, specialty crops, livestock, and pollinator habitat. For each factor, greater radial distance from the center denotes a higher weight and, therefore, greater importance in the agrivoltaics adoption decision of solar developers.

Appendix A. SWOT Results

Table A.3: SWOT priorities by solar energy scale.

SWOT Categories	**Factor Priority**					**Global Priority**				
	Full Sample	**Solar Energy Project Scales**				**Full Sample**	**Solar Energy Project Scales**			
		Large Utility	**Small Utility**	**Medium**	**Small**		**Large Utility**	**Small Utility**	**Medium**	**Small**
Strengths (S)						*0.23*	*0.17*	*0.12*	*0.13*	*0.10*
S1: Strong commercial drive	0.14	0.17	0.12	0.13	0.10	0.03	0.03	0.02	0.02	0.01
S2: Dual revenue stream	0.25	0.26	0.24	0.25	0.30	0.06	0.04	0.03	0.03	0.03
S3: Community support	**0.47**	**0.43**	**0.49**	**0.49**	**0.51**	0.11	0.07	0.06	0.06	0.05
S4: Appealing aesthetics	0.14	0.14	0.15	0.13	0.09	0.03	0.02	0.02	0.02	0.01
Weaknesses (W)						*0.15*	*0.26*	*0.24*	*0.26*	*0.30*
W1: Require more land	0.12	0.17	0.12	0.13	0.09	0.02	0.04	0.03	0.03	0.03
W2: Limited agrivoltaics adoption	0.13	0.26	0.24	0.26	0.35	0.02	0.07	0.06	0.06	0.09
W3: Coordination difficulty	0.29	**0.43**	**0.49**	**0.48**	**0.46**	0.04	0.11	0.12	0.13	0.15
W4: Higher risk/liability	**0.47**	0.14	0.15	0.13	0.09	0.07	0.04	0.04	0.03	0.03
Opportunities (O)						***0.34***	***0.43***	***0.49***	***0.48***	***0.51***
O1: Solar into farmlands	0.17	0.17	0.12	0.13	0.09	0.06	0.07	0.06	0.06	0.05
O2: Reduce operational cost	0.21	0.26	0.24	0.25	0.35	0.07	0.11	0.12	0.12	0.18
O3: Reduce community opposition	**0.44**	**0.43**	**0.49**	**0.49**	**0.46**	**0.15**	**0.19**	**0.24**	**0.23**	**0.24**
O4: Gaining reputation	0.18	0.14	0.15	0.13	0.09	0.06	0.06	0.07	0.06	0.05
Threats (T)						*0.28*	*0.14*	*0.15*	*0.13*	*0.09*
T1: Lack of funds	0.16	0.17	0.12	0.13	0.09	0.04	0.02	0.02	0.02	0.01
T2: Novel technology risk	0.23	0.26	0.24	0.26	0.35	0.06	0.04	0.04	0.03	0.03
T3: Lack of regulatory assurances	0.23	**0.43**	**0.49**	**0.48**	**0.46**	0.06	0.06	0.07	0.06	0.05
T4: Lack of policy incentives	**0.39**	0.14	0.15	0.13	0.09	0.11	0.02	0.02	0.02	0.01
Sample Size (N)	*47*	*18*	*17*	*27*	*6*	*47*	*18*	*17*	*27*	*6*

Notes: Factor priorities represent the relative importance of each factor within their respective SWOT categories. Global priorities reflect the overall weight of each factor in determining strategic importance both within and across SWOT categories. Values are derived from AHP-based weighting. The categorization of energy scale are as follows: large utility scale = 20+ MW, small utility scale = 5MW to 20 MW, medium scale = 100KW to 5 MW, and small scale = below 100 KW projects.

Table A.4: SWOT priorities by number of energy markets solar developers operate.

SWOT Categories	**Factor Priority**					**Global Priority**				
	Full Sample	**Number of Markets**				**Full Sample**	**Number of Markets**			
		Single	**2-3**	**4-5**	**6+**		**Single**	**2-3**	**4-5**	**6+**
Strengths (S)						*0.23*	*0.14*	*0.15*	*0.13*	*0.14*
S1: Strong commercial drive	0.14	0.14	0.15	0.13	0.14	0.03	0.02	0.02	0.02	0.02
S2: Dual revenue stream	0.25	0.23	0.32	0.25	0.22	0.06	0.03	0.05	0.03	0.03
S3: Community support	**0.47**	**0.45**	**0.43**	**0.49**	**0.51**	0.11	0.06	0.06	0.07	0.07
S4: Appealing aesthetics	0.14	0.18	0.10	0.12	0.12	0.03	0.03	0.02	0.02	0.02
Weaknesses (W)						*0.15*	*0.23*	*0.32*	*0.22*	*0.22*
W1: Require more land	0.12	0.14	0.15	0.13	0.14	0.02	0.03	0.05	0.03	0.03
W2: Limited agrivoltaics adoption	0.13	0.23	0.32	0.22	0.22	0.02	0.05	0.10	0.06	0.05
W3: Coordination difficulty	0.29	**0.45**	**0.43**	**0.52**	**0.51**	0.04	0.10	0.14	0.11	0.11
W4: Higher risk/liability	**0.47**	0.18	0.10	0.12	0.12	0.07	0.04	0.03	0.03	0.03
Opportunities (O)						***0.34***	***0.45***	***0.43***	***0.52***	***0.51***
O1: Solar into farmlands	0.17	0.14	0.15	0.13	0.14	0.06	0.06	0.06	0.07	0.07
O2: Reduce operational cost	0.21	0.23	0.32	0.25	0.22	0.07	0.10	0.14	0.13	0.11
O3: Reduce community opposition	**0.44**	**0.45**	**0.43**	**0.49**	**0.51**	**0.15**	**0.20**	**0.18**	**0.26**	**0.26**
O4: Gaining reputation	0.18	0.18	0.10	0.12	0.12	0.06	0.08	0.04	0.06	0.06
Threats (T)						*0.28*	*0.18*	*0.10*	*0.12*	*0.12*
T1: Lack of funds	0.16	0.14	0.15	0.13	0.14	0.04	0.03	0.02	0.02	0.02
T2: Novel technology risk	0.23	0.23	0.32	0.25	0.22	0.06	0.04	0.03	0.03	0.03
T3: Lack of regulatory assurances	0.23	**0.45**	**0.43**	**0.49**	**0.51**	0.06	0.08	0.04	0.06	0.06
T4: Lack of policy incentives	**0.39**	0.18	0.10	0.12	0.12	0.11	0.03	0.01	0.02	0.02
Sample Size (N)	*47*	*15*	*11*	*8*	*13*	*47*	*15*	*11*	*8*	*13*

Notes: Factor priorities represent the relative importance of each factor within their respective SWOT categories. Global priorities reflect the overall weight of each factor in determining strategic importance both within and across SWOT categories. Values are derived from AHP-based weighting.

Table A.5: SWOT priorities by agricultural enterprises.

SWOT Categories	**Factor Priority**					**Global Priority**				
	Full Sample	**Agricultural Enterprises**				**Full Sample**	**Agricultural Enterprises**			
		Row	**Specialty**	**Livestock**	**Pollinators**		**Row**	**Specialty**	**Livestock**	**Pollinators**
Strengths (S)						*0.23*	*0.10*	*0.12*	*0.14*	*0.14*
S1: Strong commercial drive	0.14	0.10	0.12	0.14	0.14	0.03	0.01	0.02	0.02	0.02
S2: Dual revenue stream	0.25	0.25	0.25	0.23	0.24	0.06	0.03	0.03	0.03	0.03
S3: Community support	**0.47**	**0.52**	**0.49**	**0.49**	**0.48**	0.11	0.05	0.06	0.07	0.07
S4: Appealing aesthetics	0.14	0.12	0.14	0.14	0.14	0.03	0.01	0.02	0.02	0.02
Weaknesses (W)						*0.15*	*0.25*	*0.25*	*0.23*	*0.24*
W1: Require more land	0.12	0.10	0.12	0.14	0.14	0.02	0.03	0.03	0.03	0.03
W2: Limited agrivoltaics adoption	0.13	0.25	0.25	0.24	0.25	0.02	0.06	0.06	0.06	0.06
W3: Coordination difficulty	0.29	**0.52**	**0.49**	**0.48**	**0.47**	0.04	0.13	0.12	0.11	0.11
W4: Higher risk/liability	**0.47**	0.12	0.14	0.14	0.14	0.07	0.03	0.03	0.03	0.03
Opportunities (O)						***0.34***	***0.52***	***0.49***	***0.49***	***0.48***
O1: Solar into farmlands	0.17	0.10	0.12	0.14	0.14	0.06	0.05	0.06	0.07	0.07
O2: Reduce operational cost	0.21	0.25	0.25	0.23	0.25	0.07	0.13	0.12	0.11	0.12
O3: Reduce community opposition	**0.44**	**0.52**	**0.49**	**0.49**	**0.47**	**0.15**	**0.27**	**0.24**	**0.24**	**0.23**
O4: Gaining reputation	0.18	0.12	0.14	0.14	0.14	0.06	0.06	0.07	0.07	0.07
Threats (T)						*0.28*	*0.12*	*0.14*	*0.14*	*0.14*
T1: Lack of funds	0.16	0.10	0.12	0.14	0.14	0.04	0.01	0.02	0.02	0.02
T2: Novel technology risk	0.23	0.25	0.25	0.24	0.24	0.06	0.03	0.03	0.03	0.03
T3: Lack of regulatory assurances	0.23	**0.52**	**0.49**	**0.48**	**0.48**	0.06	0.06	0.07	0.07	0.07
T4: Lack of policy incentives	**0.39**	0.12	0.14	0.14	0.14	0.11	0.01	0.02	0.02	0.02
Sample Size (N)	*47*	*11*	*13*	*27*	*25*	*47*	*11*	*13*	*27*	*25*

Notes: Factor priorities represent the relative importance of each factor within their respective SWOT categories. Global priorities reflect the overall weight of each factor in determining strategic importance both within and across SWOT categories. Values are derived from AHP-based weighting.

Appendix B. Survey Instrument

Solar Developer Survey on Agrivoltaics

Dear Stakeholders,

We are conducting a survey to understand solar developers' perspectives about agrivoltaics. Specifically, we would like to understand the strengths, weaknesses, opportunities and threats associated with the adoption of agrivoltaics technology. Your responses will help inform our recommendations about the technological changes and policy incentives needed to induce adoption of agrivoltaics. The survey will take about 15 minutes to complete. We appreciate your active participation.

This research is funded by the United States Department of Agriculture. Detailed information about the project can be found at [redacted website of the project]. All your information will remain confidential and be aggregated and anonymized before publication. We will share the aggregated findings with you and your company. There is no direct risk or incentive for participating in the survey. We assume that you consent to us using the data provided through this survey by filling in and submitting the survey. You may choose not to participate at any time and quit the survey by closing your internet browser. Feel free to contact us for more information about this research:

- Redacted Name and Email IDs of Researchers
- Redacted Name and Email IDs of Researchers

You may contact the [redacted organization name] Institutional Review Board (IRB) Office at [redacted email ID] or [redacted phone number] and the Office for the Protection of Research Subjects (OPRS) at the [redacted organization name] at [redacted email ID] or [redacted phone number] for questions about your right as survey participant.

Sincerely:

[Redacted Name and Organizations of Researchers]

[Redacted Name and Organizations of Researchers]

[Redacted IRB Approval Stamps and Logo of the Project]

Survey Context: Solar Developer Survey on Agrivoltaics

Agrivoltaics combines crops with photovoltaic systems on the same land to mitigate land use conflicts between solar energy and crop production. Co-locating solar with crops (agrivoltaics) has the potential to reduce community opposition, operational cost, and land use conflict often faced by solar developers by increasing community acceptance and access to high solar potential land.

Source: https://www.thegazette.com/

In this study, we are interested in agrivoltaic projects which may require increasing row spacing to 18-42 ft. and panel height to 6-12 ft. We request you to thoughtfully answer the following questions about your company's perspectives on the future of agrivoltaic systems.

[Redacted IRB Approval Stamps and Logo of the Project]

Section A: General question about agrivoltaics development

Please answer the following questions based on your current and future agrivoltaics project development.

1. Which scale of agrivoltaic projects is your solar company **currently developing (select all that apply)?**

   ☐ Large Utility-scale (Above 20 MW) agrivoltaics

   ☐ Small Utility-scale (5 MW to 20 MW) agrivoltaics

   ☐ Medium-scale (100 KW to 5 MW) agrivoltaics

   ☐ Small-scale (Less than 100 KW) agrivoltaics

   ☐ Other (*specify*): _________________

   ☐ None

2. Which types of agrivoltaic projects is your solar company **currently developing (select all that apply)**?

   ☐ Agrivoltaics with row crops (e.g., corn, wheat, soy)

   ☐ Agrivoltaics with specialty crops (e.g., broccoli, squash, lettuce)

   ☐ Agrivoltaics with pollinator habitat

   ☐ Agrivoltaics with livestock (e.g., sheep, cattle)

   ☐ Other (*specify*): _________________________

   ☐ None

3. Which type of agrivoltaics project is your solar company most interested in developing **in the next five years** (select one)?

   ☐ Agrivoltaics with row crops (e.g., corn, wheat, soy)

   ☐ Agrivoltaics with specialty crops (e.g., broccoli, squash, lettuce)

   ☐ Agrivoltaics with pollinator habitat

   ☐ Agrivoltaics with livestock (e.g., sheep, cattle)

   ☐ Other (*specify*): _________________

   ☐ None

4. At what scale is your solar company most interested in developing agrivoltaic projects **in the next five years** (select one)?

   ☐ Large Utility-scale (Above 20MW) agrivoltaics

   ☐ Small Utility-scale (5 MW to 20MW) agrivoltaics

   ☐ Medium-scale (100KW to 5MW) agrivoltaics

☐ Small-scale (Less than 100KW) agrivoltaics

☐ Other (*specify*): _________________

☐ None

Section B: General question about solar operation

Please answer the following questions based on your current solar energy company's operation.

5. Does your solar company have any **solar projects** in the United States?

   ☐ Yes ☐ No

6. In which region(s) has your solar company operated over the last five years **(Select all that apply)?**

   ☐ Northwest ☐ CAISO ☐ Southwest

   ☐ SPP ☐ ERCOT ☐ MISO

   ☐ Southeast ☐ PJM ☐ NYISO

   ☐ ISO-NE ☐ Other Regions/Countries (Specify: _____________)

7. What scale of **solar projects** does your solar company typically **develop (select all that apply)**?

   ☐ Large Utility-scale (Above 20 MW)

   ☐ Small Utility-scale (5 MW to 20 MW)

   ☐ Medium-scale (100 KW to 5 MW)

   ☐ Small-scale (Less than 100 KW)

8. Which of the following departments of your solar company do you belong to? **(select one)**

   ☐ Corporate Management ☐ Project Management ☐ EPC

   ☐ Finance and Accounting ☐ Marketing ☐ Others (Specify: _______)

<u>Section c: Your company's perspectives on strengths, weaknesses, opportunities, and threats for agrivoltaics adoptions:</u>

We identified potential strengths, weaknesses, opportunities, and threats for solar developers to adopt agrivoltaic in the United States.

Strengths represent ***positive factors internal*** to solar companies that may motivate the development of an agrivoltaics project	**Weaknesses** represent ***limiting factors internal*** to solar companies that pose challenges to the development of an agrivoltaics project
1: Strong commercial drive for agrivoltaics **2:** Dual revenue stream from solar and agriculture **3:** Community support and acceptance of solar with agrivoltaics **4:** Appealing aesthetics of agrivoltaics than solar alone	**1:** Agrivoltaics require more land than solar alone **2:** Limited adoption of agrivoltaics by other solar developers **3:** Difficulty of coordinating operations with farmers/landowners **4:** Higher risk and liability during project development, operation, and management
Opportunities represent ***positive factors external*** to solar companies that motivate the solar industry to develop agrivoltaic projects	**Threats** represent ***limiting factors external*** to solar companies that pose challenges to the development of agrivoltaics projects
1: Expanding solar into rural farmlands **2:** Reducing vegetation management and operational cost **3:** Reducing community opposition to solar **4:** Gaining reputation as agrivoltaics leader	**1:** Lack of investment funds for agrivoltaics (e.g., loan, microfinance) **2:** Commercial risk associated with novel technology **3:** Lack of regulatory assurances to support agrivoltaics **4:** Lack of policy incentives for agrivoltaics (e.g., tax credits)

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<u>Please read the following example and instructions carefully. Later, we will ask you to make similar pairwise comparisons.</u>

We would like you to compare the relative importance of factors pairwise (e.g., “A vs. B” and “B vs. C” in the table below). If both factors are equally important, put an X under 1. If the factor on the left is more important, put an X in one of the boxes on the left of 1. If the factor on the right is more important, put an X in one of the boxes on the right of 1.

<table>
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<tr><td colspan="11">1 = Both are equally important, 3 = Somewhat more important, 5 = Much more important, 7 = Extremely more important, 9 = Absolutely more important</td></tr>
<tr><td></td><td>9</td><td>7</td><td>5</td><td>3</td><td>1</td><td>3</td><td>5</td><td>7</td><td>9</td><td></td></tr>
<tr><td>A</td><td>X</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>B</td></tr>
<tr><td>B</td><td></td><td></td><td></td><td></td><td></td><td>X</td><td></td><td></td><td></td><td>C</td></tr>
</table>

STRENGTHS

Strengths represent ***positive factors internal*** to solar companies that may motivate the development of agrivoltaics projects. **We would like you to compare the relative importance of the factor on the left with the factor on the right by putting "X" in one box per pair based on the given scale below.**

The importance of the factor on the left side increases relative to the factor on the right as the scale moves to the left from 3 to 9					1 = Both are equally important	The importance of the factor on the right side increases relative to the factor on the left as the scale moves to the right from 3 to 9				
1 = Both are equally important, 3 = Somewhat more important, 5 = Much more important, 7 = Extremely more important, 9 = Absolutely more important										
	9	**7**	**5**	**3**	**1**	**3**	**5**	**7**	**9**	
Strong commercial drive for agrivoltaics										Dual revenue stream from solar and agriculture
Strong commercial drive for agrivoltaics										Community support and acceptance of solar with agrivoltaics
Strong commercial drive for agrivoltaics										Appealing aesthetics of agrivoltaics than solar alone
Dual revenue stream from solar and agriculture										Community support and acceptance of solar with agrivoltaics
Dual revenue stream from solar and agriculture										Appealing aesthetics of agrivoltaics than solar alone
Community support and acceptance of solar with agrivoltaics										Appealing aesthetics of agrivoltaics than solar alone

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WEAKNESSES

Weaknesses represent ***limiting factors internal*** to solar companies that challenge developing agrivoltaic projects. **We would like you to compare the relative importance of the factor on the left with the factor on the right by putting "X" in one box per pair based on the given scale below.**

The importance of the factor on the left side increases relative to the factor on the right as the scale moves to the left from 3 to 9					1 = Both are equally important	The importance of the factor on the right side increases relative to the factor on the left as the scale moves to the right from 3 to 9				
1 = Both are equally important, 3 = Somewhat more important, 5 = Much more important, 7 = Extremely more important, 9 = Absolutely more important										
	9	**7**	**5**	**3**	**1**	**3**	**5**	**7**	**9**	
Agrivoltaics require more land than solar alone										Limited adoption of agrivoltaics by other solar developers
Agrivoltaics require more land than solar alone										Difficulty of coordinating operations with farmers/landowners
Agrivoltaics require more land than solar alone										Higher risk and liability during project development, operation, and management
Limited adoption of agrivoltaics by other solar developers										Difficulty of coordinating operations with farmers/landowners
Limited adoption of agrivoltaics by other solar developers										Higher risk and liability during project development, operation, and management
Difficulty of coordinating operations with farmers/landowners										Higher risk and liability during project development, operation, and management

OPPORTUNITIES

Opportunities represent ***positive factors external*** to solar companies that motivate the solar industry to develop agrivoltaic projects. **We would like you to compare the relative importance of the factor on the left with the factor on the right by putting "X" in one box per pair based on the given scale below.**

The importance of the factor on the left side increases relative to the factor on the right as the scale moves to the left from 3 to 9					1 = Both are equally important	The importance of the factor on the right side increases relative to the factor on the left as the scale moves to the right from 3 to 9				
1 = Both are equally important, 3 = Somewhat more important, 5 = Much more important, 7 = Extremely more important, 9 = Absolutely more important										
	9	**7**	**5**	**3**	**1**	**3**	**5**	**7**	**9**	
Expanding solar into rural farmlands										Reducing vegetation management and operational cost
Expanding solar into rural farmlands										Reducing community opposition to solar
Expanding solar into rural farmlands										Gaining reputation as agrivoltaics leader
Reducing vegetation management and operational cost										Reducing community opposition to solar
Reducing vegetation management and operational cost										Gaining reputation as agrivoltaics leader
Reducing community opposition to solar										Gaining reputation as agrivoltaics leader

THREATS

Threats represent ***limiting factors external*** to solar companies that challenge developing agrivoltaic projects. **We would like you to compare the relative importance of the factor on the left with the factor on the right by putting "X" in one box per pair based on the given scale below.**

The importance of the factor on the left side increases relative to the factor on the right as the scale moves to the left from 3 to 9					1 = Both are equally important	The importance of the factor on the right side increases relative to the factor on the left as the scale moves to the right from 3 to 9				
1 = Both are equally important, 3 = Somewhat more important, 5 = Much more important, 7 = Extremely more important, 9 = Absolutely more important										
	9	**7**	**5**	**3**	**1**	**3**	**5**	**7**	**9**	
Lack of investment funds for agrivoltaics (e.g., loan, microfinance)										Commercial risk associated with novel technology
Lack of investment funds for agrivoltaics (e.g., loan, microfinance)										Lack of regulatory assurances to support agrivoltaics
Lack of investment funds for agrivoltaics (e.g., loan, microfinance)										Lack of policy incentives for agrivoltaics (e.g., tax credits)
Commercial risk associated with novel technology										Lack of regulatory assurances to support agrivoltaics
Commercial risk associated with novel technology										Lack of policy incentives for agrivoltaics (e.g., tax credits)
Lack of regulatory assurances to support agrivoltaics										Lack of policy incentives for agrivoltaics (e.g., tax credits)

Overall Comparison of Strengths, Weakness, Opportunities, and Threats

Finally, **compare the overall importance of strengths, weaknesses, opportunities, and threats that may affect the development of agrivoltaics projects.** We would like you to compare the relative importance of the factors on the left with those on the right by putting “X” in one box per pair based on the given scale below.

The importance of the factor on the left side increases relative to the factor on the right as the scale moves to the left from 3 to 9					1 = Both are equally important	The importance of the factor on the right side increases relative to the factor on the left as the scale moves to the right from 3 to 9				
1 = Both are equally important, 3 = Somewhat more important, 5 = Much more important, 7 = Extremely more important, 9 = Absolutely more important										
	9	**7**	**5**	**3**	**1**	**3**	**5**	**7**	**9**	
Internal positive motivating factors to develop agrivoltaic projects										*Internal negative* challenges to develop agrivoltaic projects
Internal positive motivating factors to develop agrivoltaic projects										*External positive* factors motivating to develop agrivoltaic projects
Internal positive motivating factors to develop agrivoltaics projects										*External negative* challenges to develop agrivoltaic projects
Internal negative challenges to develop agrivoltaic projects										*External positive* factors motivating to develop agrivoltaic projects
Internal negative challenges to develop agrivoltaics projects										*External negative* challenges to develop agrivoltaic projects
External positive factors motivating factors to develop agrivoltaics projects										*External negative* challenges to develop agrivoltaics projects

9. If you would like to provide additional feedback, please do so in the box below:

We appreciate your participation in this research.

You may now send the survey to us in the attached pre-paid and self-addressed envelope.

If you misplaced the pre-paid and self-addressed envelope, please mail the survey to us at:

[Redacted Name and Mailing Address of a Researcher]

For further contact

[Redacted Name and Email IDs]

Abstract

The rapid expansion of solar energy on US farmland faces land-use conflicts and community opposition. Agrivoltaics is proposed as a middle-ground solution, but which factors will influence a solar developer's decision to adopt agrivoltaics remain under-explored. We examined factors that will influence a developer's decision to adopt agrivoltaics as well as the current status and future interests in agrivoltaics development in the US. Our findings show that reducing community opposition to large scale solar energy projects is the strongest driver of agrivoltaics adoption, carrying more than a 25% weight in their decisions. At the same time, developers face challenges such as coordination difficulties, a lack of regulatory assurances, and perceived risks associated with novel dual-use technology. Despite such challenges, we found that solar developers are building several agrivoltaics projects across the country and are interested in developing more in the future. Addressing barriers related to limited policy incentives, regulatory uncertainty, coordination challenges, and perceived risks will be critical to accelerating agrivoltaics development in the US.

Keywords: Community Opposition, Solar in Farmland, SWOT-AHP, Solar Developers, Novel Technology Risk

1. Introduction

Solar energy is a domestic, low-emissions energy resource with significant potential to support long-term energy supply, energy security, and grid reliability. It can significantly reduce the environmental footprint of global energy consumption while supporting long-term global sustainability goals through 2050 [1]. The US has expanded solar energy capacity at a faster rate than any other energy source as part of broader efforts to reduce the environmental impacts of energy production [2] Achieving this scale of deployment has land-use implications, with solar development projected to require between four and eleven million acres across the contiguous US [3].

To achieve this ambitious goal, large utility scale photovoltaic solar energy projects are being developed in rural farmlands in the US [4]. Farmland is particularly suitable for large scale solar energy development because it combines high solar potential with accessible locations, proximity to the electric grid, favorable slopes and environmental conditions, and the availability of large contiguous tracts for utility scale projects [5]. About 93% of solar energy projects are being developed in rural US out of which 70% are installed on farmland [6]. In New York State, for instance, about 44% of existing utility-scale solar projects are developed on agricultural land, and around 84% of the suitable land for solar development is agricultural land, including about 35% of active farmland in one of its counties [7]. About 80% of new solar projects built in US are excepted to be on farmland by 2040 [8]. About 1.1% to 2.4% of the US cropland will be converted to photovoltaics to meet solar energy targets by 2050 [9], corresponding to approximately 4.2 to 9.2 million acres of cropland, based on total US cropland reported in the 2022 Census of Agriculture [10]. The expansion of solar energy projects at this scale with such an enormous land requirement causes community opposition which is a major challenge for solar developers to build solar energy projects across the US [11, 12].

A study tracking opposition for renewable energy across the US found that, in 2024, 459 counties or municipalities across 44 states imposed restrictions on renewable energy siting—16% more than in 2023 [13]. Opposition groups raised enough voice to influence decision-making process delaying or canceling solar energy projects in Michigan [14]. In western and northern New York, about 42% of the resident opposed large utility scale solar installation in the communities [15]. A nationwide survey of solar developers found that about 60% of the solar projects are delayed by at least six months and about 40% of the projects are canceled in the last five years [16]. The cost per successful project is significantly higher than the average cost spent per project due to project cancellations [17]. The unrecoverable average sunk cost per solar project is about $2 million per project and the average lost due to project delay is about $30,000 per megawatt [16]. A recent advancement in solar energy technological development opens a possibility of co-locating solar energy system with agricultural crops, also called as agrivoltaics [18].

The purpose of this study is to understand solar developer's motivations and barriers for agrivoltaics adoption in the US. More specifically, we examine the current state of agrivoltaics development from the perspective of solar developers in the US, developer's future interest in adopting agrivoltaics, and the key motivations and barriers influencing technology adoption decisions. Solar developers spend large amount of time, money, and effort to gain community support to develop solar projects [11]. Understanding developer's current development activities, future interests, and perceived drivers and constraints can inform the design of targeted incentives, help reduce adoption barriers, and improve the overall acceptance of agrivoltaics projects among solar developers. Greater acceptance of agrivoltaics among developers may, in turn, lower investment costs associated with community opposition to large scale solar projects and accelerate the deployment of agrivoltaics in the US.

We surveyed solar developer across the US to understand their motivation and barriers of agrivoltaics adoption. We used strengths, weaknesses, opportunities, and threats analytical hierarchical process (SWOT-AHP) to understand positive and negative aspects of agrivoltaics adoption. This is a multi-criteria decision analysis approach which commonly used in strategic management [19] by structuring and solving problems that involves multiple criteria such as strengths, weaknesses, opportunities, and threats [20, 21]. This method is useful in solving a problem where multiple solutions appear to be equally important and thus, differentiation of items based on public opinion is essential to prioritize multiple solutions. SWOT-AHP has wider application in various fields such as growth of the renewable energy sector

[22], natural resource management [23], and sustainable waste management [24].

SWOT-AHP is appropriate for emerging technologies like agrivoltaics where developer's perceptions plays a critical role in shaping early adoption trajectories but data availability remains limited due to early phase of technological innovation and the confidentiality of project-level information [25]. This method provides sufficiently structured yet relatively flexible approach to quantify and prioritize relative importance of identified factors, enabling consistent, evidence-based decision-making [26]. The SWOT-AHP approach effectively captured solar developer's macro-level motivations and barriers to agrivoltaics adoption in the US, providing valuable insights for strategic planning and policy interventions to support agrivoltaics development.

Agrivoltaics is advocated as a solution to overcoming community opposition to large scale solar [27, 28]. This is a novel technology that co-locates solar energy with agricultural enterprises such as crops, livestock, and pollinators, providing an alternative solution to standalone solar energy projects. It is relatively more favored by farmers [29], public, and government officials [30, 31] compared to standalone solar projects. Agrivoltaics increases land-use efficiency and diversifies farm-revenue stream while providing access to quality land for solar energy projects [29, 32]. However, a benefit-cost assessment of agrivoltaics project suggests that it requires a significant amount of incentives and policy support to make it as profitable as standalone solar [33]. More importantly, agrivoltaics needs a far more complicated technological shift, larger capital investment cost, and significantly more land compared to standalone solar to facilitate agricultural operations [34].

Solar developers play a crucial role in advancing agrivoltaics technology. Their technical knowledge and experience of developing standalone solar can be valuable in the development of agrivoltaic projects. However, the understanding of developer's motivations and barriers to adopt agrivoltaics is very limited. So far, only a few studies have explored developers perspective on agrivoltaics adoption [30, 31]. These studies are also confined to local or regional level providing a limited understanding of developer's insight on agrivoltaics adoption at the national level. A lack of understanding of their motivation and barriers may hinder technology adoption, diffusion, and expansion, thus, weakening potential of agrivoltaics to contribute towards achieving the electrification goal. Understanding developer's motivation and barrier for agrivoltaics adoption is essential to overcome agrivoltaics adoption barriers, balance agrivoltaics profitability with community interests, and align policy incentives with sustainability goals to meet net-zero emission target. The lack of such understanding often result into disengagement of solar developers in the technology development process [35].

This paper contributes to the growing literature on agrivoltaics adoption by studying motivations and barriers influencing solar developer's decision to adopt agrivoltaics system across the US. These motivations and barriers were identified through the series of focus group discussions among developers across the US and synthesized to key sixteen determinants of agrivoltaics adoption at the current early stage of technological advancement. These factors were, then, adapted into SWOT-AHP survey framework to study their relative importance. Our results indicate that the opportunity to reduce community opposition for large scale solar is the biggest factor for solar developers to adopt agrivoltaics. Other factors are related to energy policy, project management, technology risks, and finances. We further quantified the influence of each factor in the adoption decisions. We found that community opposition alone accounts for more than one-fourth of the overall decision-making process related to the technology adoption. Finally, we discuss how these factors vary by energy scale, agricultural enterprise type, and regional energy market characteristics [36].

In addition, we captured current state of agrivoltaics development in the US using close ended single and multiple-choice questions. We further studied solar developer's future interest in adopting agrivoltaics technology. We found that a large majority of solar developers are currently developing medium to large scale agrivoltaics projects mostly with livestock and pollinator habitat. About 60% solar developers are interested in developing 5MW or above sized agrivoltaics. We further found that about 59% of solar developers are interested in developing agrivoltaics with livestock and specialty crops.

The rest of the paper is organized as follows: section 2 outlines focus group discussions and defines the SWOT factors followed by the methods in section 3. The method section includes survey design, data collection, SWOT-AHP process, and empirical framework. Section 4 presents results describing demographics of solar developers, current and future of agrivoltaics development trends, and motivations and barriers of agrivoltaics adoption using SWOT-AHP. The motivations and barriers are discussed based on the full sample as well as grouping them by solar energy scales, number of energy markets, and agricultural enterprises. Finally, section 5 discusses study findings and policy implications and section 6 concludes the study.

2. Focus Group Discussions and SWOTs of Agrivoltaics

In this section, we briefly discuss focus group discussions and identification process of SWOT factors, followed by the definition and a brief discussion of these factors (Table 1). These factors were presented to solar developers for pairwise comparisons in the survey. For the purpose of this study, we consider these factors as motivators or barriers of agrivoltaics for solar developers to adopt agrivoltaic projects in the US.

Table 1 (Table with SWOT Factors) Here

2.1. Focus Group Discussions

We conducted six focus group discussions with solar developers, each session having a unique combination of participants, averaging five developers per discussion. The first discussion was held on the third quarter of 2022 with twelve developers. We explored their perspectives on the current status of agrivoltaic projects development and willingness to adopt the technology.

We, then, conduced one focus group discussion with six farmers in the same quarter of 2022. Following the insight from two discussion sessions, we designed a behavioral experiment-based discrete choice model (DCE) survey to assess developer's willingness to adopt agrivoltaics. The survey instrument was then pilot-tested in the second focus group discussion with solar developers.

Based on feedback from subsequent discussions, we adopted SWOT-AHP framework instead of DCE, as the DCE was less well suited to the current context of agrivoltaics research for three key reasons. First, agrivoltaics adoption is shaped by a wide range of economic, social, and regulatory considerations that are difficult to represent comprehensively within a DCE framework. Second, confidentiality considerations surrounding cost information posed a limitation on revealing monetary values through DCE. Third, the hypothetical nature of DCE scenarios, combined with the early stage of agrivoltaics development, constrained respondent's ability to reliably evaluate and compare DCE alternatives.

SWOT-AHP integrates qualitative insights with quantitative pairwise comparisons, enabling developers to systematically prioritize strengths, weaknesses, opportunities, and threats. This approach provides a feasible and structured method for establishing a baseline understanding of solar developers' motivations and challenges in adopting agrivoltaics at the early stage of its development [25]. From the researcher's perspective, this method allows us to capture subtle differences and complexities in developer's decision making which are directly applicable for informing policy interventions. Thus, we identified several motivating and limiting factors of agrivoltaics and distilled down to sixteen factors that external and internal to agrivoltaics which either motivates or restricts its adoption among developers. Finally, we formalized sixteen factors into strengths, weaknesses, opportunities, and threats (SWOTs) developing a SWOT-AHP framework to study developer's motivation and barriers of agrivoltaics adoption.

2.2. Strengths of Agrivoltaics

Strengths are positive characteristics internal to agrivoltaics that motivates solar developers to adopt agrivoltaics. Strengths of agrivoltaics for a solar developers include: a strong commercial drive, a dual revenue stream, community support and acceptance of solar, and appealing aesthetics compared to standalone solar. The strong commercial appeal of agrivoltaics arises from cost savings due to lower sunk costs, ease of permitting and regulatory processes [31], as well as easier access to land with high solar potential that is well connected to the electric grid [5]. Agrivoltaics generates dual revenue stream from crops and solar energy production without negatively affecting land productivity [37]. Past research has reported that solar receives more support from community if it is integrated with agricultural production [27]. Finally, Agrivoltaics is perceived as a more aesthetically pleasing form of solar technology than conventional solar projects [27] because of its natural integration of plants in the system design.

2.3. Weaknesses of Agrivoltaics

Weaknesses are negative characteristics internal to agrivoltaics that discourages solar developers to adopt agrivoltaics. Weaknesses of agrivoltaics include: requiring more land than standalone solar, limited adoption, coordination difficulty and higher risk and liability. Though agrivoltaics is a potential proposed solution for land competition between food and energy production, it requires more land than conventional solar energy projects due to the inter-panel spacing to accommodate crops and cultural operations [38]. Consolidating land parcels to secure sufficiently large tracts for utility scale agrivoltaics poses a significant challenge for solar developers due to distributed land ownership, variable land valuation, complex decision-making processes, community opposition, and concerns over farmland preservation and land restoration. These issues arise coordination difficulties between developers and farmers/landowners [39, 31]. Another challenges of agrivoltaics is higher risk and safety liabilities during project development, operation, and management because of frequent agricultural activities in the agrivoltaics site [31, 30]. Finally, the adoption of agrivoltaics technology is very limited among solar developers resulting in lack of experience and limited data availability, especially at its current early development stage. This leads to higher capital investment costs [39]. The limited data availability on system performance further makes investment decision complicated for solar developers [39, 30].

2.4. Opportunities of Agrivoltaics

Opportunities are positive characteristics external to agrivoltaics that motivate solar developers to adopt the technology. Major opportunities associated with agrivoltaics adoption are: expanding solar into rural farmlands, reducing vegetation management and operational costs, reducing community opposition to solar, and gaining reputation as a agrivoltaics leader. The broader acceptance of agrivoltaics among agricultural communities [39, 31] presents a strategic opportunity for solar developers to expand solar development on farmland through agrivoltaics adoption. Adopting agrivoltaics early potentially establish solar developers as agrivoltaics leaders, which puts them in competitive advantage position in the solar business [39, 30]. Another appealing aspect of agrivoltaics is reducing vegetation management and operational costs by replacing unnecessary vegetation with agricultural enterprises such as crops, livestock, and pollinators, which is an additional external benefit beyond the food and energy production goal of agrivoltaics [39, 40].

2.5. Threats of Agrivoltaics

Threats are negative characteristics external to agrivoltaics that discourages solar developers to adopt agrivoltaics, such as lack of external investment funds, commercial risks associated with novel technology, lack of regulatory assurance to support agrivoltaics, and lack of policy incentive. [31] reported that solar developers were concerned about financial burden and challenge to identify investors for agrivoltaics compared to standalone solar. Commercial risks arise because agrivoltaics challenges the standardized, low-risk business model that underpins utility scale solar development. The absence of long-term performance data, unclear risk allocation across stakeholders, and higher upfront capital costs [41] increase perceived risks, limiting adoption despite its potential social and land-use benefits. The investment in agrivoltaics technology is further limited by the lack of regulatory support and policy incentives [39, 29]. In many instances, agrivoltaics is opposed at local to national levels and policies are less supportive towards agrivoltaics development [13, 42]. Furthermore, existing policies, such as tax credits, are primarily designed to incentivize standalone solar projects and are not yet sufficiently tailored to promote agrivoltaics adoption [42, 43]. The uncertainty around long term support of incentives and policies [44], restrictive land-use policy, zoning regulations, ambiguity in defining agrivoltaics further limits agrivoltaics development [43, 45].

3. Method

3.1. Survey Design and Data Collection

We designed a solar developer survey with three distinct sections. The first section provided brief background information about agrivoltaics, and specified agrivoltaics system configuration. Particularly, we specified agrivoltaics in the survey as solar panels mounted on 6-12 ft. tall metallic poles with 18-42 ft. row spacing and were co-located with crops for energy and food production. Then we described the context of the survey, and requested developers to thoughtfully answers survey questions. The second section collected information on respondents' experience with traditional solar and agrivoltaic projects, followed by questions assessing their interest in pursuing agrivoltaics development in the future. In the third section, we provided an example demonstration SWOT pairwise comparison process (Figure 1) and asked respondents to follow the same process to compare SWOT factors within strengths, weaknesses, opportunities, and threats categories. Finally, we asked respondents to make pairwise comparisons of overall strength, weakness, opportunity, and threat at the end of the survey. We followed this approach to reduce survey fatigue and lower response rate in the second set (Appendix B). The SWOT factors represented motivations and barriers of agrivoltaics for solar stakeholder to adopt the technology in the US.

Figure 1 (SWOT Factor Comparison Example) Here.

We disseminated online and paper versions of the survey from July to December 2024. The online version of the survey was emailed to solar developers using solar stakeholder database jointly developed by Sustainably Colocating Agricultural and Photovoltaic Electricity Systems (SCAPES) project, solar industry partners, and solar stakeholder working groups. For the survey dissemination we collected information such as company type, program affiliations, websites, email, vendor IDs, and phone numbers from 213 solar company websites. We removed duplicate information which resulted in

179 unique and verified email IDs and updated contact information. The final consolidated database from all sources resulted into a list of 250 solar developers across the country. We followed up twice via email reminding solar developers to fill out the survey. We also disseminated the online survey to solar developers through solar industry partner organizations such as Solar and Storage Industries Institute (SI2), Solar Energy Industries Association (SEIA), and American Solar Grazing Association (ASGA). We further distributed paper-printed version of the survey at two agrivoltaics specific conferences (Solar Farm Summit and World Agrivoltaics Conference) and one solar energy industry trade show (RE+).

We reached out to 300 solar developers through online and paper surveys and received 100 completed surveys resulting into 33% response rate. Pairwise deletion approach was employed to handle missing data during SWOT analysis resulting into 47% sample size retention rate. Our sample size is comparable with past studies adopting SWOT-AHP framework in their study [23]. Past research has reported challenge in receiving responses from solar developers for survey studies [39]. SWOT-AHP is a tool that can accommodate small sample size when SWOT factors are carefully selected in the presence of industry practitioners, professionals, and experts.

3.2. SWOT-AHP Process

SWOT-AHP is a two-step process of identifying SWOT factors and deriving scale of priorities (or weights) of the factors. The joint SWOT-AHP process overcomes limitations of qualitative nature of SWOT by assigning quantitative weight and ranking factors [46]. Weights indicate relative importance of ranked factors in the decision-making process based on respondent's subjective judgment. The first step of identifying SWOT factors is described in the focus group discussion section. In the second step, we generated a set of six pairwise combinations of factors within each category to compare their relative importance (Figure 1). Then, we asked solar developers to make pairwise comparisons on a scale of 1 to 9. If the pair received 1, both factors in the pair are equally important. The factor receiving 3 to 9 in the pairwise comparison set is 3 to 9 times more important than the second factor [26] indicated by the green lines with outward pointed arrow and the text description above it (Figure 1). This process was repeated for strengths, weaknesses, opportunities, and threats. At the end, we asked developers to make a pairwise comparison among strengths, weaknesses, opportunities, and threats (Appendix B).

3.3. Empirical Framework

Let $\mathbf{W} = (a_{ij})$ be an $n \times n$ positive reciprocal pairwise comparison matrix with properties

$$a_{ij} = \frac{w_i}{w_j}, \quad a_{ii} = 1, \quad a_{ji} = \frac{1}{a_{ij}}, \quad \forall i, j \in \{1, \ldots, n\},\ i \neq j, \quad n = 4, \qquad (1)$$

where i and j index the SWOT factors being compared.

$$\mathbf{W} = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \frac{w_1}{w_3} & \frac{w_1}{w_4} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \frac{w_2}{w_3} & \frac{w_2}{w_4} \\ \frac{w_3}{w_1} & \frac{w_3}{w_2} & \frac{w_3}{w_3} & \frac{w_3}{w_4} \\ \frac{w_4}{w_1} & \frac{w_4}{w_2} & \frac{w_4}{w_3} & \frac{w_4}{w_4} \end{bmatrix} \quad \mathbf{w} = \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ w_4 \end{bmatrix} \tag{2}$$

The matrix $\mathbf{W}$ measures how strongly one SWOT factor is preferred over another, based on the judgments of solar developers. Intuitively, w_i represents the relative importance of factor i, and $a_{ij} = w_i/w_j$ indicates how many times more important factor i is compared to factor j. In the perfectly consistent case[1], the pairwise comparisons satisfy $a_{ij} = w_i/w_j$. In empirical applications, however, $\mathbf{W}$ is constructed from judgment data and may deviate from this exact ratio. In this case, the priority vector $\mathbf{w}$ is derived from $\mathbf{W}$ by computing the principal eigenvector and normalizing it so that $\sum_{i=1}^{n} w_i = 1$ [46].

Assuming $\mathbf{W}$ is positive and $\mathbf{w} > 0$, a perfectly consistent comparison matrix satisfies

$$\mathbf{W}\mathbf{w} = n\mathbf{w}. \tag{3}$$

The underlying priority of each factor is captured by the vector

$$\mathbf{w} = (w_1, w_2, w_3, w_4)^\top, \tag{4}$$

[1] A perfectly consistent case is one in which all pairwise judgments align exactly with one another, so that the implied importance ratios follow transitive logic through the corresponding multiplied ratios. The perfectly consistent comparison matrix yields a principal eigenvalue equal to n.

where $w_i > 0$ is the priority weight of factor i, $\mathbf{w}$ is the normalized principal eigenvector of $\mathbf{W}$.

The principal eigenvalue of $\mathbf{W}$, denoted $\lambda_{\max}$, satisfies:

$$\mathbf{W}\mathbf{w} = \lambda_{\max}\mathbf{w}, \quad w_i = \frac{v_i}{\sum_{k=1}^{4} v_k}, \tag{5}$$

with v_i being the i^{th} component of the principal eigenvector. This normalization converts the weights into relative proportions, allowing for clear interpretation and comparison of the importance of each factor across categories.

The eigenvalues, λ, are solutions to

$$\det(\mathbf{W} - \lambda\mathbf{I}) = 0, \tag{6}$$

where $\mathbf{I}$ is the $n \times n$ identity matrix.

Matrix $\mathbf{W}$ is perfectly consistent if and only if $\lambda_{\max} = n$; deviations of $\lambda_{\max}$ from n indicate inconsistency. Inconsistency measures the extent to which a solar developer's pairwise comparisons violate the proportional logic of a perfectly consistent judgment.

The Consistency Index (CI), the measure of how much developer's pairwise comparisons deviate from perfect logical consistency, is defined as

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1}. \tag{7}$$

The Consistency Ratio (CR) evaluates whether the inconsistency is acceptable:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}, \tag{8}$$

where RI is the average consistency index of a randomly generated reciprocal matrix of order n. CR < 0.10 indicates an acceptable level of consistency. For $n = 4$, RI $= 0.89$ [46].

Local or factor priorities (within-category weights) are calculated separately for each SWOT category such that the sum of factor weights within each category equals one. Let $w_{i|C}$ denote the local priority of factor i, called as local/factor priority, in SWOT category C. Then, for each category:

$$\sum_{i \in C} w_{i|C} = 1, \quad \forall\, C \in \{\mathrm{S, W, O, T}\}, \tag{9}$$

where S = Strengths, W = Weaknesses, O = Opportunities, and T = Threats.

Global priorities are obtained by multiplying local priorities by the weight of their parent category, denoted W_C. The global priority (overall weight) of factor i is therefore:

$$w_i^{\mathrm{global}} = W_C \cdot w_{i|C}, \quad i \in C. \tag{10}$$

The sum of all global priorities across all sixteen SWOT factors satisfies:

$$\sum_{C \in \{\mathrm{S, W, O, T}\}} \sum_{i \in C} w_i^{\mathrm{global}} = 1. \tag{11}$$

All AHP-derived priorities are non-negative. For interpretation in the agrivoltaics adoption context, global priorities associated with Weaknesses and Threats are assigned a negative sign to reflect their adverse influence, while Strengths and Opportunities retain positive signs.

$$w_i^{\text{global}} = \begin{cases} > 0, & \text{for Strengths and Opportunities,} \\ < 0, & \text{for Weaknesses and Threats.} \end{cases} \tag{12}$$

4. Results

4.1. Demographics of Solar developers

All solar developers who participated in the study reported that their company has operated in the US in the last five years. Our study represents solar developers operating throughout the US, and at varied stages of business development from new solar developers entering into the US energy market, to established solar developers actively operating in the regional to national energy markets. About 93% of solar developers reported that their company has operated photovoltaic solar projects in the US. The remaining 7% are currently developing new photovoltaic solar projects in the US. Many of our participants operated in more than one [36] designated electric power markets in the last five years (Figure 2). The top four energy markets in which our respondents operated in the last five years were Mid-continent (MISO, 64%), PJM interconnection (PJM, 61%), New York (NYISO, 45%), and Southeast (SE, 43%). Among survey respondents, 31% of developers operated in a single U.S. energy market, while 14% operated in two markets, 15% in three markets, 13% in four to five markets, and 27% in six or more markets.

Figure 2 (Distribution map of developers) Here

We asked solar developers to indicate all the scale categories of photovoltaic solar project that their solar company typically develops among following four energy scale categories: 20+MW (large utility), 5MW to 20MW (small utility), 100KW to 5MW (medium), and below 100KW (small). About 43% of solar developers develop large utility scale, 38% develop small utility scale, 60% develop medium scale, and 15% develop small scale photovoltaic solar energy projects. About 65% of the developers developed photovoltaic solar energy projects within a single category of energy scales whereas 15% solar developers develop energy projects in two, 18% in three, and 2% in four solar energy scale categories mentioned above. In response to the question regarding developer's departmental affiliation within their solar companies, 22% of respondents reported working in engineering, procurement, and construction, followed by marketing (20%), corporate management (17%), finance (5%), and project management (2%). About 34% indicated their affiliation with other departments in their solar company.

4.2. Current and Future of Agrivoltaics Development Trends

Survey responses show that a large majority of solar developers are currently developing medium scale to large utility scale agrivoltaic projects (Table 2). About 96% of the solar developers expressed interest in developing

100KW or larger agrivoltaic projects in the next five years, out of which majority of the developers are interested in developing 5MW or larger agrivoltaic projects.

Table 2 (Current status and future interests in agrivoltaics adoption) Here.

Regarding the type of agrivoltaics projects, we found that solar develops have developed more than one type of agrivoltaics. About 59% of solar developers are developing agrivoltaics with livestock, 49% with pollinator habitat, 30% with specialty crops, 25% with row crops, and 14% with other crops. About 14% of our respondents are not developing any agrivoltaics projects. Further, we found that about 29% solar developers mentioned that their company is interested in developing agrivoltaics with livestock, 25% with specialty crops, 21% with row crops, 16% with pollinator habitat, and 6% with other crops within the five years. However, about 3% developers mentioned that their solar company is not interest in developing agrivoltaics projects in the US in the same period.

Figure 3 (Currently Developing agrivoltaics projects in the US) Here.

Combining energy scale and agricultural enterprise types from the total reported agrivoltaic projects in the survey, the largest share of projects currently being developed in the US are medium scale (100 kW to 5 MW) projects with livestock (52%) and pollinator habitat (40%). (Figure: 3). About 32% and 34% of solar developers are developing large utility scale

(20+MW) agrivoltaic projects with livestock and pollinator habitat, respectively. Similarly, about 32% and 30% developers are building medium scale agrivoltaics with specialty crops and small scale (Below 100 KW) agrivoltaics with livestock respectively.

Overall, the results indicate that agrivoltaics deployment in the US is already oriented toward medium to large utility scale projects. Solar developers are showing strong interest in further scaling up their agrivoltaics projects over the next five years. Agrivoltaics with livestock and pollinator dominate current and near-future development of agrivoltaics compared to crop based agrivoltaics.

4.3. SWOT-AHP: Motivations and Barriers of Agrivoltaics Adoption

Motivations and barriers for the adoption of agrivoltaics by solar developers were summarized based on the full sample, solar energy scale (Table A.3 and Figure 4), US energy markets (Table A.4 and Figures 5), and agricultural enterprises (Table A.5 and Figure 6). In addition to the full sample, classifying SWOTs by energy scale, energy markets, and agricultural enterprises allows us to capture the heterogeneous motivations and barriers faced by different types of solar developers under diverse farming contexts across all US energy markets. This disaggregation ensures that strategic priorities and policies are tailored based on the need of developers prioritizing specific energy scale, energy markets, and agricultural enterprises for agrivoltaics development. Solar developers were grouped into respective energy scale and crop enterprise categories based on current status of agrivoltaics development by their solar company.

The factor receiving the highest weight in factor and global priorities within each SWOT category are bolded in each of the three summary tables. The consistency ratio (CR) values for all SWOT categories in the summary tables were less than 0.10, indicating that the results across all categories are within the acceptable threshold of the consistency index [46]. The highest factor priority weight represents the most important factor within each SWOT category. The highest global priority weight represents the most important factor among all SWOT factors.

4.3.1. SWOT Priorities for the Full Sample

The factor priority and global priority weights of SWOT factors based on the full sample are reported in the first column under factor and global priorities respectively in the table A.3[2] and global priorities are visualized as grey lines spider web plots in figure 4[3]. Our analysis showed that solar developers considered the opportunities presented by agrivoltaics to be the most important factor, assigning them an average priority weight of 34%. This was followed by threats (28%), strengths (23%), and weaknesses (15%),

[2]Factor and global priorities for full sample are reported in Tables A.3, A.4, and A.5 to compare results between the full sample and respective categories. Full sample results in all three tables are identical.

[3]Global priorities for full sample are also visualized in Figures 4, 5, and 6 to compare results between the full sample and respective categories. Full sample results in all three figures are identical.

indicating that developers are most focused on potential benefits and external challenges when evaluating agrivoltaics adoption. The smallest priority weight received by weaknesses suggests that the benefits of agrivoltaics outweighs the its limitations in solar developers decision to adopt agrivoltaics. Strengthening external opportunities and addressing concerns about external threats are crucial in motivating solar developers to adopt agrivoltaics.

Considering all SWOT factors based on global priority weight for the full sample, reducing community opposition for solar (opportunity, 15%) is the biggest motivating factor for solar developers to adopt agrivoltaics. The community support for agrivoltaics (strengths, 11%) and lack of policy incentives (threat, 11%) are positive and negative factors which ranked as the second equally most important motivator and barrier for agrivoltaics adoption. Similarly, higher risk and liability (weakness, 7%) and reducing operational cost (opportunity, 7%) are two equally important SWOT factor ranked in the third position that affect solar stakeholder's agrivoltaics adoption decision.

4.3.2. SWOT Priorities Based on Solar Energy Scale

The influence of SWOT factors on the decision of solar developers to adopt agrivoltaics varies with the energy scale of agrivoltaics. Comparing global priorities of SWOT factors across all the project scales, we found that the opportunity to reduce community opposition for solar energy projects remains as the most important factor influencing developer's agrivoltaics adoption decision (Table A.3 and Figure 4). For large utility scale and medium scale developers, the weights are 19% and 23% respectively and that for small utility and small scale developers is equal (24%). Coordination difficulty, a weakness, and the opportunity to reduce operational cost were ranked as the second most important factors influencing agrivoltaics decision by large utility scale (11%) and small utility scale (12%) solar developers. Medium and small scale solar developers mentioned coordination difficulty (weakness, 13%) and reducing operational cost (opportunity, 18%) as the second most important factors in their respective decisions to adopt agrivoltaics technology.

Figure: 4 (Energy Scale Spider Plot) Here

For large utility scale developers, community support (strength, 7%), limited agrivoltaics adoption (weakness, 7%), and expanding solar into farmland (opportunity, 7%) remained as the third most but equally important factors affecting agrivoltaics adoption decision (Table A.3 and Figure 4). Small utility scale developers viewed gaining reputation as an agrivoltaics leader (opportunity, 7%) and the lack of regulatory assurances (threat, 7%) as the third most important factors influencing their decision on agrivoltaics adoption. Medium and small scale solar developers identified reducing operational cost (opportunity, 12%) and coordination difficulty (weakness, 15%), respectively, as the third most important factors influencing their agrivoltaics adoption decision.

4.3.3. SWOT Priorities Based on Energy Markets

We estimated priority for solar developers by grouping them into the number of regions they are operating in the US (Table A.4 and Figure 5). They were grouped in four categories: single, 2-3, 4-5, and 6+ energy markets. Opportunity to reduce community opposition for solar energy ranked as the top priority for solar developers to adopt agrivoltaics regardless of number of energy markets they are operating in. This result shows that community opposition to solar is a major barrier for solar energy project development across the country. The priority weights for the factor vary based on the number of regions operated, suggesting that impact of community opposition on decision making of solar developers varies with the with the energy markets. The smallest weight for the community opposition on decision making is 18% among developers operating in 2-3 regions. This weight is, however, larger than the weight assigned to the factor by the full sample of solar developers. The findings suggest that locally operating developers may be better positioned to navigate community concerns. This highlights an opportunity to leverage agrivoltaics as a socially acceptable pathway for solar deployment in regions with limited prior exposure to large-scale solar projects.

Figure: 5 (Energy Market Spider Plot) Here

The priority weight of opportunity to reduce community opposition to solar is 0.26 (26%) for developers operating in four or more energy markets (Table A.4) suggesting that more than one fourth of their decision to adopt agrivoltaics is influenced by the opportunity to reduce community opposition to solar. These solar developers consider community opposition as relatively more important factor in their decision to adopt agrivoltaics as compared to those operating in three or less regions. This suggests that the national-level developers place greater emphasis on reducing community opposition for solar in their agrivoltaics adoption decision compared to developers operating in local or regional markets.

Opportunity to reduce operational cost ranked in the second position for all solar developers. Coordination difficulty also remains as the third most important factor influencing the decision to adopt agrivoltaics for all solar developers except those operating in 4-5 energy markets. Even though the weight of each factor varies with the number of energy markets, the weight of above factors ranking in second and third positions are close to each other suggesting that their impacts on solar developer's decision to adopt agrivoltaics is about the same. Compared to top two highly ranked factors, the third most important factor affecting the decision to adopt agrivoltaics varies more widely across four categories of energy markets.

Solar developer's third most important factors influencing agrivoltaics adoption vary by number of energy markets. Developers operating in a single region emphasized gaining a reputation as agrivoltaics leaders (opportunity, 8%) and lack of regulatory assurance (threat, 8%). In contrast, developers operating in 2–3 and 4–5 energy markets identified limited adoption (weakness, 10%) and coordination difficulty (weakness, 11%), respectively, as their third most important factors. For developers operating in 6+ energy markets, expanding solar into farmland (opportunity, 7%) and community support for agrivoltaics (strength, 7%) were equally important.

These patterns suggest that single-region developers are more concerned with reputation-building and regulatory clarity, which can help reduce community opposition and create a more level playing field [47]. In contrast, developers operating across multiple regions appear more focused on scaling up agrivoltaics deployment, emphasizing coordination, land access, and community support to enable larger-scale project development.

4.3.4. SWOT Priorities Based on Agricultural Enterprises

We further classified SWOT priorities based on agricultural enterprises (Table A.5 and Figure 6). Opportunity to reduce community opposition to solar energy projects remains the most important factor influencing solar developer's decision to adopt agrivoltaics. The weights range from 23% to 27% depending upon agricultural enterprises suggesting about one fourth of the effort on decision making is devoted to the effort to reduce community opposition for solar energy projects. The second most important factors for solar developers operating agrivoltaics with row crops, specialty crops, and livestock are the opportunity to reduce operational cost and barriers due to coordination difficulty with landowners/farmers. For solar developers operating agrivoltaics with pollinator habitat, reducing operational cost is the second most important factor affecting the decision to adopt agrivoltaics.

Figure: 6 (Ag Enterprise Spider Plot) Here

Several factors ranked as the third most important factors influencing solar developer's decision to adopt agrivoltaics, which also vary with the agricultural enterprise types. Solar developers with row crop agrivoltaics indicated that limited agrivoltaics adoption (weakness, 6%), gaining a reputation as agrivoltaics leader (opportunity, 6%) and lack of regulatory assurances for agrivoltaics (threat, 6%) are the three equally important factors affecting their decision to adopt agrivoltaics. For solar developers operating agrivoltaics with specialty crops, the third most important factors are lack of regulatory assurances (threat, 7%) and gaining reputation as agrivoltaics leader (opportunity, 7%). However, solar developers operating agrivoltaics with livestock stated that the community support for agrivoltaics (strength, 7%), converting solar into farmland (opportunity, 7%), gaining reputation as agrivoltaics leader (opportunity, 7%), and lack of regulatory assurance (threat, 7%) as four equally important factors ranked in third place affecting their agrivoltaics adoption decision. For solar developers with pollinator habitat, coordination difficulty (weakness, 11%) was the third most important factor affecting their decision to adopt agrivoltaics.

5. Discussion and Policy Implication

This study evaluated relative importance of sixteen motivations and barriers to agrivoltaics adoption among solar developers in the US. We explored these factors from multiple dimensions based on solar energy scale, US solar energy markets, and types of agricultural enterprises using SWOT-AHP approach. We found that decision to adopt agrivoltaics is highly influenced by the external factor such opportunities and threats compared to internal factors such as strengths and weaknesses. The opportunity to reduce community opposition emerge as the most important factors accounting for about 25% weight in solar developer's decision to adopt agrivoltaics regardless solar energy scale, number of energy markets, or agricultural enterprise types. This suggests that the lack of social acceptance for solar is a significant binding constraints on solar development than financial or technical challenges.

Agrivoltaics can be an pathway to reduce community opposition for large scale solar because it is generally perceived as a more acceptable form of solar energy projects than standalone solar [27, 47]. For solar developers, community opposition has been one of the major cost drivers of solar energy projects [15, 27]. A survey of utility scale solar developers found that at least 30% of the solar energy projects were canceled and about 60% were significantly delayed in the US and the community opposition is among the top three reasons for the cancellation or the delay [16]. To overcome such social backlashes, solar developers are adopting various strategies such as meetings, workshops, community engagement, and adjustment to project design [11]. However, addressing local environmental and livelihood concerns such as losing farmland to solar [35] may require strategic planning and implementation throughout the energy project initiation and development cycle. Agrivoltaics co-locates solar with local agricultural enterprises with minimal disruption to the local agricultural land, farmer's livelihood, and environment which could be a more acceptable solution while simultaneously expanding solar in farmland. Agrivoltaics, by its nature, has flexibility to address such concerns about standalone solar. Thus, agrivoltaics could potentially be a viable pathway to promote utility scale solar energy expansion while simultaneously addressing community concerns about standalone solar project and mutually benefiting solar developers, farmers, and the community.

Besides, several other factors have relatively small but impactful in the solar developer's decision to adopt agrivoltaics. Such positive factors are opportunity to expand solar into farmland, gaining reputation as agrivoltaics leader in the community, and community support for agrivoltaics. While the first benefit is naturally embedded with system configuration of agrivoltaics, solar developers continuous effort to address local community, livelihood, and farmland preservation concerns through agrivoltaics adoption would potentially establish them as an agrivoltaics leader in the community [31, 30]. Similarly, relatively small but negatively impacting in solar developer's decision to adopt agrivoltaics are lack of policy incentives, and lack of regulatory assurances, risk and liability associated with novelty of technology. For example, Massachusetts agrivoltaics policy is considered as an example because of its clearly defined solar sitting standard in farmland but, the policy is also criticized as inadequate due to its non-mandatory and continuously changing guidelines [45]. Such conflicting provisions in policies can limit scaling opportunities and create mixed outcomes for agrivoltaics development [45, 48]. The continuously changing priorities of governments at various levels on renewable energy technologies including agrivoltaics creates a long-term commitment vacuum adding uncertainty in adoption, research, technology advancement, and policy formulation [13]. Bringing such clarity in the policy, regulation, and long-term commitments are crucial in advancing agrivoltaics development in the US [45, 43].

The rest of the factors remain as less influential than those discussed above in solar developer's decision to adopt agrivoltaics. Nonetheless, these factors should receive attention in the policy formulation processes for several reasons. First, these factors emerged from intensive multiple rounds of focus group discussions with solar developers and farmers across the US, indicating that these are among the crucial factors influencing agrivoltaics development in the US. Second, these factors have frequently emerged in several literature on agrivoltaics adoption as important factors affecting agrivoltaics development. For example, strengths such as strong commercial drive, dual revenue stream, and appealing aesthetics appear to be less influential in our study. However, solar developers and farmers value these mutual benefits arising from the increased land productivity and dual revenue stream [29, 31]. This mutual arrangement provides access to high quality rural farmland for solar developers and generates stable long-term revenue income as risk management strategy against crop failure and farm revenue decline for farmers.

Solar developers play a pivotal role in scaling up agrivoltaics. This study offers a macro-level economic assessment of the factors shaping developer's adoption decisions and strategically prioritizes the key motivators and barriers influencing the decision. The findings identify pathway for policy interventions needed in both the short and long run to accelerate agrivoltaics deployment and identify need for public policies that enhance its benefits while addressing constraints that limit developer participation. Disaggregated results by energy scale, agricultural enterprise type, and market participation reveal substantial heterogeneity in developer responses, underscoring the need for targeted policy instruments rather than one-size-fits-all approaches.

While community opposition consistently emerges as the most influential factor affecting agrivoltaics adoption, the relative importance of other factors varies widely across the full sample and subgroup categories. This variation highlights pronounced heterogeneity in developer's priorities and the impacts of secondary adoption drivers. Understanding the sources of this heterogeneity lies beyond the scope of this study and represents an important direction for future research. Ultimately, the effectiveness of policies, targeted incentives, and agrivoltaics support programs will depend on efforts to account for this heterogeneity, reduce adoption barriers, and strengthen key motivators that facilitate solar developer's adoption of agrivoltaics technologies.

6. Conclusion

This study analyzed the key motivators and challenges influencing agrivoltaics adoption among US solar developers, the current and future perspective of agrivoltaics development. We found that solar developers are motivated by opportunities associated with agrivoltaics development, particularly the potential to reduce community opposition to large scale solar projects and, in some cases, reduce operational costs. However, external factors beyond developer's control—-such as coordination difficulties with farmers and landowners, lack of policy incentives, and the absence of clear regulatory frameworks—-remain major challenges limiting agrivoltaics adoption. Despite these constraints, medium scale to large utility scale agrivoltaics projects are currently under development in the US, with several projects integrating solar energy with livestock grazing and pollinator habitat. Solar developers further express strong interest in pursuing utility scale agrivoltaics projects within the next five years. From an energy policy perspective, these findings highlight the importance of addressing existing barriers through targeted policy support, financial incentives, clear regulatory frameworks, and local ordinances that facilitate coordination between developers and farmers or landowners. Such policy interventions are essential to reduce uncertainty, improve project feasibility, and accelerate agrivoltaics deployment while advancing national electrification goals through expanded solar energy development.

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Tables

Table 1: Factors identified in each SWOT category.

Strengths (S)	**Weaknesses (W)**
S1: Strong commercial drive for agrivoltaics	**W1:** Agrivoltaics require more land than solar alone
S2: Dual revenue stream from solar and agriculture	**W2:** Limited adoption of agrivoltaics by other solar developers
S3: Community support and acceptance of solar with agrivoltaics	**W3:** Difficulty of coordinating operations with farmers/landowners
S4: Appealing aesthetics of agrivoltaics compared to solar alone	**W4:** Higher risk and liability during project development, operation, and management
Opportunities (O)	**Threats (T)**
O1: Expanding solar into rural farmlands	**T1:** Lack of investment funds for agrivoltaics (e.g., loan, microfinance)
O2: Reducing vegetation management and operational cost	**T2:** Commercial risk associated with novel technology
O3: Reducing community opposition to solar	**T3:** Lack of regulatory assurances to support agrivoltaics
O4: Gaining reputation as agrivoltaics leader	**T4:** Lack of policy incentives for agrivoltaics (e.g., tax credits)

Notes: SWOT = Strengths, Weaknesses, Opportunities, and Threats. We conducted several focus group discussions with solar developers from 2022 and 2024. Strengths and Opportunities are internal and external positive factors of agrivoltaics that motivates solar developers to adopt agrivoltaics. Weaknesses and Threats are internal and external negative factors of agrivoltaics that demotivates solar developers to adopt agrivoltaics.

Table 2: Current and future interest in agrivoltaics project development by energy scale categories.

Energy Scale	**Currently Developing**	**In the Next 5 Years**
Large Utility Scale (20+ MW)	40%	37%
Small Utility Scale (5 MW—20 MW)	33%	26%
Medium Scale (100 KW—5 MW)	52%	34%
Small Scale (Below 100 KW)	14%	2%
None	-	2%
Total Sample (N)	63	62

Notes: One solar developer selected more than one energy scales. So, the sum of percentage for the "Currently Developing" column is more than 100%. Values were rounded to the nearest whole number.

Figures

<u>Please read the following example and instructions carefully. Later, we will ask you to make similar pairwise comparisons.</u>

We would like you to compare the relative importance of factors pairwise (e.g., "A vs. B" and "B vs. C" in the table below). If both factors are equally important, put an X under 1. If the factor on the left is more important, put an X in one of the boxes on the left of 1. If the factor on the right is more important, put an X in one of the boxes on the right of 1.

The importance of the factor on the left side increases relative to the factor on the right as the scale moves to the left from 3 to 9					1 = Both are equally important	The importance of the factor on the right side increases relative to the factor on the left as the scale moves to the right from 3 to 9				
1 = Both are equally important, 3 = Somewhat more important, 5 = Much more important, 7 = Extremely more important, 9 = Absolutely more important										
	9	**7**	**5**	**3**	**1**	**3**	**5**	**7**	**9**	
A	**X**									**B**
B						**X**				**C**

Figure 1: SWOT Example presented to solar stakeholder before asking to make a pairwise comparison.

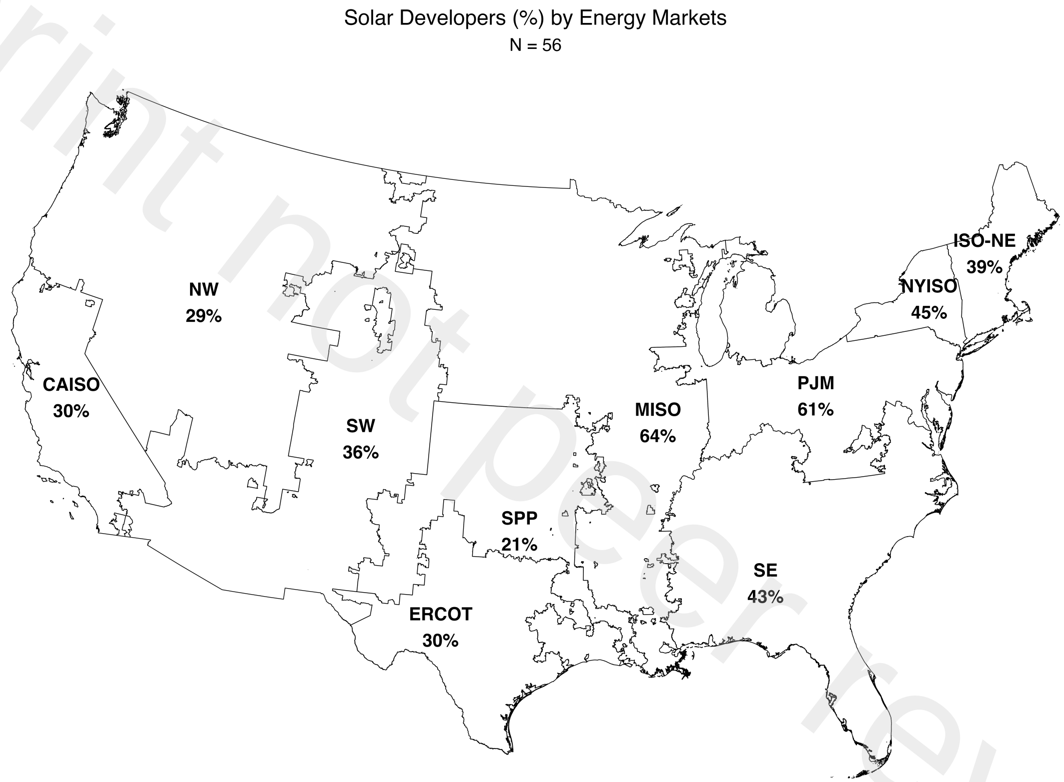


Figure 2: Geographical Distribution of solar developers

Notes: This map shows regional distribution of our survey participant's solar company operating over the last five years. A single solar developer is operating in more than one energy markets which is why the sum of percentages is more than 100%. CAISO = California, NW = Northwest, SW = Southwest, ERCOT = Texas, SPP = Southwest Power Pool, MISO = Mid-continent, SE = South east, PJM = PJM Inter-connection, NYISO = New York, ISO-NE = New England.

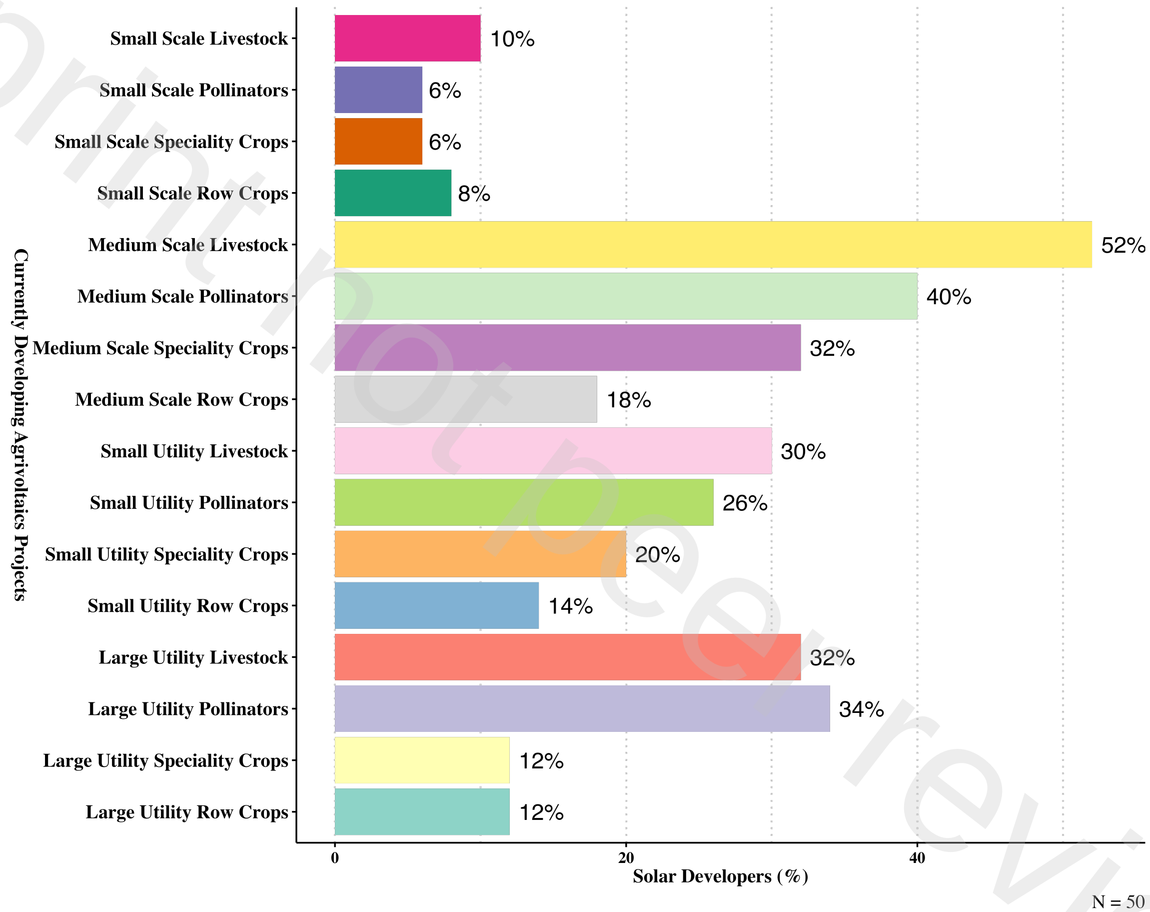
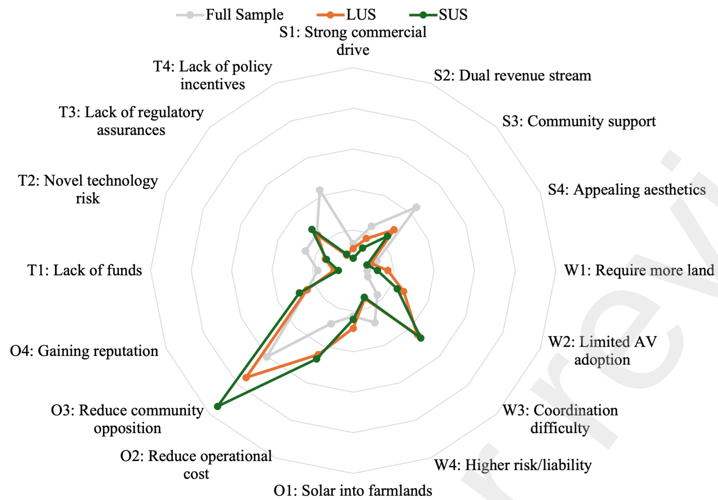
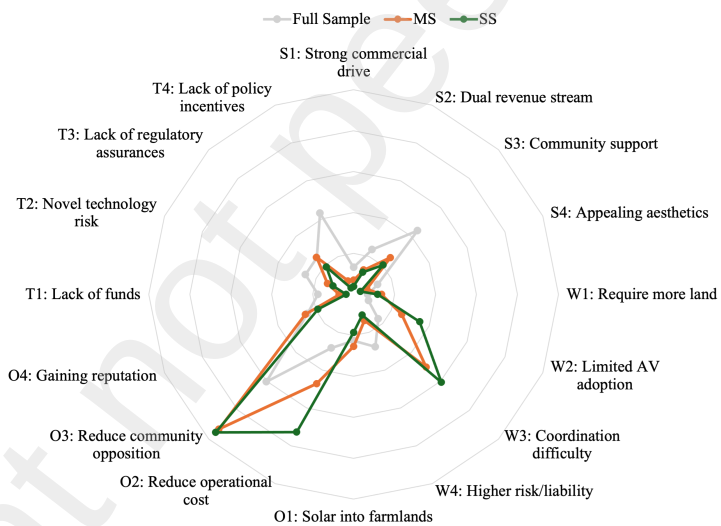


Figure 3: Currently developing agrivoltaics projects in the US.

Notes: Percentages are rounded to the nearest whole number. The sum of percentage is more than 100% because single developers selected more than one option. This chart was developed by cross-tabbing two questions from the survey that provides information about currently developing agrivoltaics projects by energy scale (Appendix B, question 1) and agricultural enterprise (Appendix B, question 2) types.



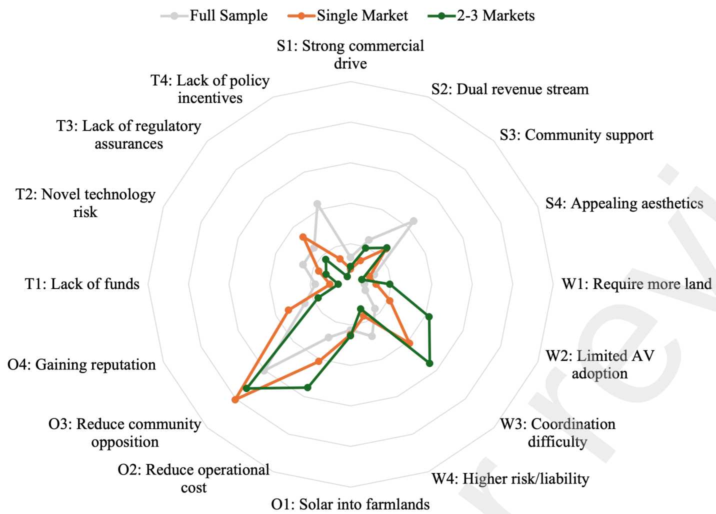
(a)



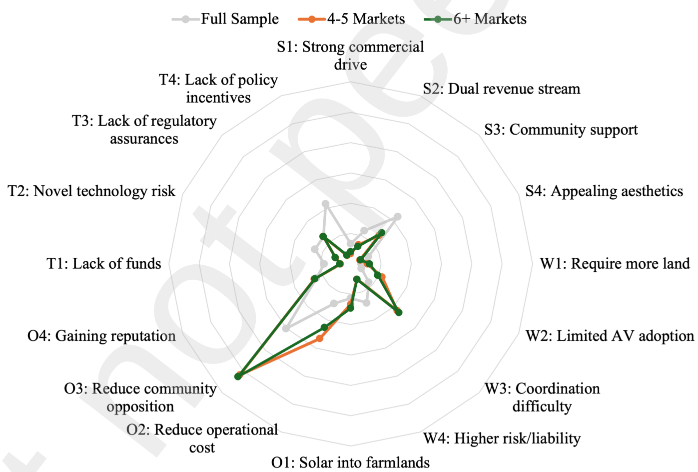
(b)

Figure 4: Comparative distribution of SWOT factor's global priorities by solar energy scales and the full sample.

Notes: The spider chart illustrates differences in weighting patterns across the full sample (Full Sample), large utility scale (LUS), small utility scale (SUS), medium scale (MS), and small scale (SS) solar developers, with colors distinguishing each group. For each factor, greater radial distance from the center denotes a higher weight and, therefore, greater importance in the agrivoltaics adoption decision.



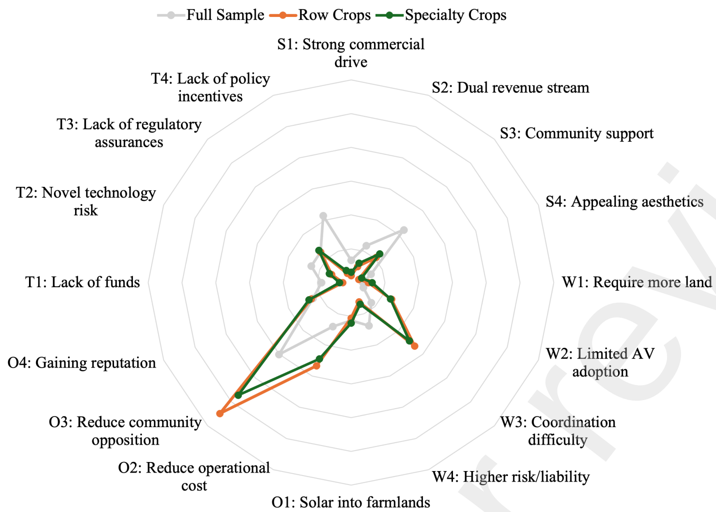
(a)



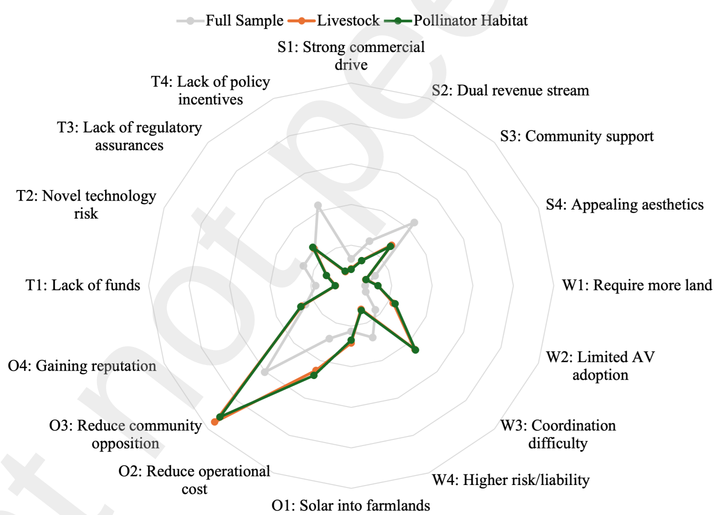
(b)

Figure 5: Comparative distribution of SWOT factor's global priorities by US energy markets and the full sample.

Notes: The spider chart illustrates differences in weighting patterns across full sample of solar developers and developers operating in single market, 2-3 energy markets, 4-5 energy markets, and 6+ energy markets across the US. For each factor, greater radial distance from the center denotes a higher weight and, therefore, greater importance in the solar developer's agrivoltaics adoption decision.



(a)



(b)

Figure 6: Comparative distribution of SWOT factor's global priorities by agricultural enterprises and the full sample.

Notes: The spider chart illustrates differences in weighting patterns across the full sample (Full Sample) and various agricultural enterprises such as row crops, specialty crops, livestock, and pollinator habitat. For each factor, greater radial distance from the center denotes a higher weight and, therefore, greater importance in the agrivoltaics adoption decision of solar developers.

Appendix A. SWOT Results

Table A.3: SWOT priorities by solar energy scale.

SWOT Categories	**Factor Priority**					**Global Priority**				
	Full Sample	**Solar Energy Project Scales**				**Full Sample**	**Solar Energy Project Scales**			
		Large Utility	**Small Utility**	**Medium**	**Small**		**Large Utility**	**Small Utility**	**Medium**	**Small**
Strengths (S)						*0.23*	*0.17*	*0.12*	*0.13*	*0.10*
S1: Strong commercial drive	0.14	0.17	0.12	0.13	0.10	0.03	0.03	0.02	0.02	0.01
S2: Dual revenue stream	0.25	0.26	0.24	0.25	0.30	0.06	0.04	0.03	0.03	0.03
S3: Community support	**0.47**	**0.43**	**0.49**	**0.49**	**0.51**	0.11	0.07	0.06	0.06	0.05
S4: Appealing aesthetics	0.14	0.14	0.15	0.13	0.09	0.03	0.02	0.02	0.02	0.01
Weaknesses (W)						*0.15*	*0.26*	*0.24*	*0.26*	*0.30*
W1: Require more land	0.12	0.17	0.12	0.13	0.09	0.02	0.04	0.03	0.03	0.03
W2: Limited agrivoltaics adoption	0.13	0.26	0.24	0.26	0.35	0.02	0.07	0.06	0.06	0.09
W3: Coordination difficulty	0.29	**0.43**	**0.49**	**0.48**	**0.46**	0.04	0.11	0.12	0.13	0.15
W4: Higher risk/liability	**0.47**	0.14	0.15	0.13	0.09	0.07	0.04	0.04	0.03	0.03
Opportunities (O)						***0.34***	***0.43***	***0.49***	***0.48***	***0.51***
O1: Solar into farmlands	0.17	0.17	0.12	0.13	0.09	0.06	0.07	0.06	0.06	0.05
O2: Reduce operational cost	0.21	0.26	0.24	0.25	0.35	0.07	0.11	0.12	0.12	0.18
O3: Reduce community opposition	**0.44**	**0.43**	**0.49**	**0.49**	**0.46**	**0.15**	**0.19**	**0.24**	**0.23**	**0.24**
O4: Gaining reputation	0.18	0.14	0.15	0.13	0.09	0.06	0.06	0.07	0.06	0.05
Threats (T)						*0.28*	*0.14*	*0.15*	*0.13*	*0.09*
T1: Lack of funds	0.16	0.17	0.12	0.13	0.09	0.04	0.02	0.02	0.02	0.01
T2: Novel technology risk	0.23	0.26	0.24	0.26	0.35	0.06	0.04	0.04	0.03	0.03
T3: Lack of regulatory assurances	0.23	**0.43**	**0.49**	**0.48**	**0.46**	0.06	0.06	0.07	0.06	0.05
T4: Lack of policy incentives	**0.39**	0.14	0.15	0.13	0.09	0.11	0.02	0.02	0.02	0.01
Sample Size (N)	*47*	*18*	*17*	*27*	*6*	*47*	*18*	*17*	*27*	*6*

Notes: Factor priorities represent the relative importance of each factor within their respective SWOT categories. Global priorities reflect the overall weight of each factor in determining strategic importance both within and across SWOT categories. Values are derived from AHP-based weighting. The categorization of energy scale are as follows: large utility scale = 20+ MW, small utility scale = 5MW to 20 MW, medium scale = 100KW to 5 MW, and small scale = below 100 KW projects.

Table A.4: SWOT priorities by number of energy markets solar developers operate.

SWOT Categories	**Factor Priority**					**Global Priority**				
	Full Sample	**Number of Markets**				**Full Sample**	**Number of Markets**			
		Single	**2-3**	**4-5**	**6+**		**Single**	**2-3**	**4-5**	**6+**
Strengths (S)						*0.23*	*0.14*	*0.15*	*0.13*	*0.14*
S1: Strong commercial drive	0.14	0.14	0.15	0.13	0.14	0.03	0.02	0.02	0.02	0.02
S2: Dual revenue stream	0.25	0.23	0.32	0.25	0.22	0.06	0.03	0.05	0.03	0.03
S3: Community support	**0.47**	**0.45**	**0.43**	**0.49**	**0.51**	0.11	0.06	0.06	0.07	0.07
S4: Appealing aesthetics	0.14	0.18	0.10	0.12	0.12	0.03	0.03	0.02	0.02	0.02
Weaknesses (W)						*0.15*	*0.23*	*0.32*	*0.22*	*0.22*
W1: Require more land	0.12	0.14	0.15	0.13	0.14	0.02	0.03	0.05	0.03	0.03
W2: Limited agrivoltaics adoption	0.13	0.23	0.32	0.22	0.22	0.02	0.05	0.10	0.06	0.05
W3: Coordination difficulty	0.29	**0.45**	**0.43**	**0.52**	**0.51**	0.04	0.10	0.14	0.11	0.11
W4: Higher risk/liability	**0.47**	0.18	0.10	0.12	0.12	0.07	0.04	0.03	0.03	0.03
Opportunities (O)						***0.34***	***0.45***	***0.43***	***0.52***	***0.51***
O1: Solar into farmlands	0.17	0.14	0.15	0.13	0.14	0.06	0.06	0.06	0.07	0.07
O2: Reduce operational cost	0.21	0.23	0.32	0.25	0.22	0.07	0.10	0.14	0.13	0.11
O3: Reduce community opposition	**0.44**	**0.45**	**0.43**	**0.49**	**0.51**	**0.15**	**0.20**	**0.18**	**0.26**	**0.26**
O4: Gaining reputation	0.18	0.18	0.10	0.12	0.12	0.06	0.08	0.04	0.06	0.06
Threats (T)						*0.28*	*0.18*	*0.10*	*0.12*	*0.12*
T1: Lack of funds	0.16	0.14	0.15	0.13	0.14	0.04	0.03	0.02	0.02	0.02
T2: Novel technology risk	0.23	0.23	0.32	0.25	0.22	0.06	0.04	0.03	0.03	0.03
T3: Lack of regulatory assurances	0.23	**0.45**	**0.43**	**0.49**	**0.51**	0.06	0.08	0.04	0.06	0.06
T4: Lack of policy incentives	**0.39**	0.18	0.10	0.12	0.12	0.11	0.03	0.01	0.02	0.02
Sample Size (N)	*47*	*15*	*11*	*8*	*13*	*47*	*15*	*11*	*8*	*13*

Notes: Factor priorities represent the relative importance of each factor within their respective SWOT categories. Global priorities reflect the overall weight of each factor in determining strategic importance both within and across SWOT categories. Values are derived from AHP-based weighting.

Table A.5: SWOT priorities by agricultural enterprises.

SWOT Categories	**Factor Priority**					**Global Priority**				
	Full Sample	**Agricultural Enterprises**				**Full Sample**	**Agricultural Enterprises**			
		Row	**Specialty**	**Livestock**	**Pollinators**		**Row**	**Specialty**	**Livestock**	**Pollinators**
Strengths (S)						*0.23*	*0.10*	*0.12*	*0.14*	*0.14*
S1: Strong commercial drive	0.14	0.10	0.12	0.14	0.14	0.03	0.01	0.02	0.02	0.02
S2: Dual revenue stream	0.25	0.25	0.25	0.23	0.24	0.06	0.03	0.03	0.03	0.03
S3: Community support	**0.47**	**0.52**	**0.49**	**0.49**	**0.48**	0.11	0.05	0.06	0.07	0.07
S4: Appealing aesthetics	0.14	0.12	0.14	0.14	0.14	0.03	0.01	0.02	0.02	0.02
Weaknesses (W)						*0.15*	*0.25*	*0.25*	*0.23*	*0.24*
W1: Require more land	0.12	0.10	0.12	0.14	0.14	0.02	0.03	0.03	0.03	0.03
W2: Limited agrivoltaics adoption	0.13	0.25	0.25	0.24	0.25	0.02	0.06	0.06	0.06	0.06
W3: Coordination difficulty	0.29	**0.52**	**0.49**	**0.48**	**0.47**	0.04	0.13	0.12	0.11	0.11
W4: Higher risk/liability	**0.47**	0.12	0.14	0.14	0.14	0.07	0.03	0.03	0.03	0.03
Opportunities (O)						***0.34***	***0.52***	***0.49***	***0.49***	***0.48***
O1: Solar into farmlands	0.17	0.10	0.12	0.14	0.14	0.06	0.05	0.06	0.07	0.07
O2: Reduce operational cost	0.21	0.25	0.25	0.23	0.25	0.07	0.13	0.12	0.11	0.12
O3: Reduce community opposition	**0.44**	**0.52**	**0.49**	**0.49**	**0.47**	**0.15**	**0.27**	**0.24**	**0.24**	**0.23**
O4: Gaining reputation	0.18	0.12	0.14	0.14	0.14	0.06	0.06	0.07	0.07	0.07
Threats (T)						*0.28*	*0.12*	*0.14*	*0.14*	*0.14*
T1: Lack of funds	0.16	0.10	0.12	0.14	0.14	0.04	0.01	0.02	0.02	0.02
T2: Novel technology risk	0.23	0.25	0.25	0.24	0.24	0.06	0.03	0.03	0.03	0.03
T3: Lack of regulatory assurances	0.23	**0.52**	**0.49**	**0.48**	**0.48**	0.06	0.06	0.07	0.07	0.07
T4: Lack of policy incentives	**0.39**	0.12	0.14	0.14	0.14	0.11	0.01	0.02	0.02	0.02
Sample Size (N)	*47*	*11*	*13*	*27*	*25*	*47*	*11*	*13*	*27*	*25*

Notes: Factor priorities represent the relative importance of each factor within their respective SWOT categories. Global priorities reflect the overall weight of each factor in determining strategic importance both within and across SWOT categories. Values are derived from AHP-based weighting.

Appendix B. Survey Instrument

Solar Developer Survey on Agrivoltaics

Dear Stakeholders,
We are conducting a survey to understand solar developers' perspectives about agrivoltaics. Specifically, we would like to understand the strengths, weaknesses, opportunities and threats associated with the adoption of agrivoltaics technology. Your responses will help inform our recommendations about the technological changes and policy incentives needed to induce adoption of agrivoltaics. The survey will take about 15 minutes to complete. We appreciate your active participation.

This research is funded by the United States Department of Agriculture. Detailed information about the project can be found at [redacted website of the project]. All your information will remain confidential and be aggregated and anonymized before publication. We will share the aggregated findings with you and your company. There is no direct risk or incentive for participating in the survey. We assume that you consent to us using the data provided through this survey by filling in and submitting the survey. You may choose not to participate at any time and quit the survey by closing your internet browser. Feel free to contact us for more information about this research:

- Redacted Name and Email IDs of Researchers
- Redacted Name and Email IDs of Researchers

You may contact the [redacted organization name] Institutional Review Board (IRB) Office at [redacted email ID] or [redacted phone number] and the Office for the Protection of Research Subjects (OPRS) at the [redacted organization name] at [redacted email ID] or [redacted phone number] for questions about your right as survey participant.

Sincerely:

[Redacted Name and Organizations of Researchers]

[Redacted Name and Organizations of Researchers]

[Redacted IRB Approval Stamps and Logo of the Project]

Survey Context: Solar Developer Survey on Agrivoltaics

Agrivoltaics combines crops with photovoltaic systems on the same land to mitigate land use conflicts between solar energy and crop production. Co-locating solar with crops (agrivoltaics) has the potential to reduce community opposition, operational cost, and land use conflict often faced by solar developers by increasing community acceptance and access to high solar potential land.

Source: https://www.thegazette.com/

In this study, we are interested in agrivoltaic projects which may require increasing row spacing to 18-42 ft. and panel height to 6-12 ft. We request you to thoughtfully answer the following questions about your company's perspectives on the future of agrivoltaic systems.

[Redacted IRB Approval Stamps and Logo of the Project]

<u>Section A: General question about agrivoltaics development</u>
Please answer the following questions based on your current and future agrivoltaics project development.

1. Which scale of agrivoltaic projects is your solar company **currently developing (select all that apply)?**
   - ☐ Large Utility-scale (Above 20 MW) agrivoltaics
   - ☐ Small Utility-scale (5 MW to 20 MW) agrivoltaics
   - ☐ Medium-scale (100 KW to 5 MW) agrivoltaics
   - ☐ Small-scale (Less than 100 KW) agrivoltaics
   - ☐ Other (*specify*): _________________
   - ☐ None

2. Which types of agrivoltaic projects is your solar company **currently developing (select all that apply)**?
   - ☐ Agrivoltaics with row crops (e.g., corn, wheat, soy)
   - ☐ Agrivoltaics with specialty crops (e.g., broccoli, squash, lettuce)
   - ☐ Agrivoltaics with pollinator habitat
   - ☐ Agrivoltaics with livestock (e.g., sheep, cattle)
   - ☐ Other (*specify*): _________________________
   - ☐ None

3. Which type of agrivoltaics project is your solar company most interested in developing **in the next five years** (select <u>one</u>)?
   - ☐ Agrivoltaics with row crops (e.g., corn, wheat, soy)
   - ☐ Agrivoltaics with specialty crops (e.g., broccoli, squash, lettuce)
   - ☐ Agrivoltaics with pollinator habitat
   - ☐ Agrivoltaics with livestock (e.g., sheep, cattle)
   - ☐ Other (*specify*): _________________
   - ☐ None

4. At what scale is your solar company most interested in developing agrivoltaic projects **in the next five years** (select <u>one</u>)?
   - ☐ Large Utility-scale (Above 20MW) agrivoltaics
   - ☐ Small Utility-scale (5 MW to 20MW) agrivoltaics
   - ☐ Medium-scale (100KW to 5MW) agrivoltaics

☐ Small-scale (Less than 100KW) agrivoltaics

☐ Other (*specify*): ________________

☐ None

<u>Section B: General question about solar operation</u>

Please answer the following questions based on your current solar energy company's operation.

5. Does your solar company have any **<u>solar projects</u>** in the United States?

   ☐ Yes ☐ No

6. In which region(s) has your solar company operated over the last five years **(Select all that apply)?**

   ☐ Northwest ☐ CAISO ☐ Southwest

   ☐ SPP ☐ ERCOT ☐ MISO

   ☐ Southeast ☐ PJM ☐ NYISO

   ☐ ISO-NE ☐ Other Regions/Countries (Specify: _____________)

7. What scale of **<u>solar projects</u>** does your solar company typically **develop (select all that apply)**?

   ☐ Large Utility-scale (Above 20 MW)

   ☐ Small Utility-scale (5 MW to 20 MW)

   ☐ Medium-scale (100 KW to 5 MW)

   ☐ Small-scale (Less than 100 KW)

8. Which of the following departments of your solar company do you belong to? **(select one)**

   ☐ Corporate Management ☐ Project Management ☐ EPC

   ☐ Finance and Accounting ☐ Marketing ☐ Others (Specify: _______)

Section c: Your company’s perspectives on strengths, weaknesses, opportunities, and threats for agrivoltaics adoptions:

We identified potential strengths, weaknesses, opportunities, and threats for solar developers to adopt agrivoltaic in the United States.

Strengths represent ***positive factors internal*** to solar companies that may motivate the development of an agrivoltaics project	**Weaknesses** represent ***limiting factors internal*** to solar companies that pose challenges to the development of an agrivoltaics project
1: Strong commercial drive for agrivoltaics **2:** Dual revenue stream from solar and agriculture **3:** Community support and acceptance of solar with agrivoltaics **4:** Appealing aesthetics of agrivoltaics than solar alone	**1:** Agrivoltaics require more land than solar alone **2:** Limited adoption of agrivoltaics by other solar developers **3:** Difficulty of coordinating operations with farmers/landowners **4:** Higher risk and liability during project development, operation, and management
Opportunities represent ***positive factors external*** to solar companies that motivate the solar industry to develop agrivoltaic projects	**Threats** represent ***limiting factors external*** to solar companies that pose challenges to the development of agrivoltaics projects
1: Expanding solar into rural farmlands **2:** Reducing vegetation management and operational cost **3:** Reducing community opposition to solar **4:** Gaining reputation as agrivoltaics leader	**1:** Lack of investment funds for agrivoltaics (e.g., loan, microfinance) **2:** Commercial risk associated with novel technology **3:** Lack of regulatory assurances to support agrivoltaics **4:** Lack of policy incentives for agrivoltaics (e.g., tax credits)

<u>Please read the following example and instructions carefully. Later, we will ask you to make similar pairwise comparisons.</u>

We would like you to compare the relative importance of factors pairwise (e.g., “A vs. B” and “B vs. C” in the table below). If both factors are equally important, put an X under 1. If the factor on the left is more important, put an X in one of the boxes on the left of 1. If the factor on the right is more important, put an X in one of the boxes on the right of 1.

The importance of the factor on the left side increases relative to the factor on the right as the scale moves to the left from 3 to 9					1 = Both are equally important	The importance of the factor on the right side increases relative to the factor on the left as the scale moves to the right from 3 to 9				
1 = Both are equally important, 3 = Somewhat more important, 5 = Much more important, 7 = Extremely more important, 9 = Absolutely more important										
	9	**7**	**5**	**3**	**1**	**3**	**5**	**7**	**9**	
A	**X**									**B**
B						**X**				**C**

STRENGTHS

Strengths represent ***positive factors internal*** to solar companies that may motivate the development of agrivoltaics projects. **We would like you to compare the relative importance of the factor on the left with the factor on the right by putting “X” in one box per pair based on the given scale below.**

The importance of the factor on the left side increases relative to the factor on the right as the scale moves to the left from 3 to 9					1 = Both are equally important	The importance of the factor on the right side increases relative to the factor on the left as the scale moves to the right from 3 to 9				
1 = Both are equally important, 3 = Somewhat more important, 5 = Much more important, 7 = Extremely more important, 9 = Absolutely more important										
	9	**7**	**5**	**3**	**1**	**3**	**5**	**7**	**9**	
Strong commercial drive for agrivoltaics										Dual revenue stream from solar and agriculture
Strong commercial drive for agrivoltaics										Community support and acceptance of solar with agrivoltaics
Strong commercial drive for agrivoltaics										Appealing aesthetics of agrivoltaics than solar alone
Dual revenue stream from solar and agriculture										Community support and acceptance of solar with agrivoltaics
Dual revenue stream from solar and agriculture										Appealing aesthetics of agrivoltaics than solar alone
Community support and acceptance of solar with agrivoltaics										Appealing aesthetics of agrivoltaics than solar alone

WEAKNESSES

Weaknesses represent ***limiting factors internal*** to solar companies that challenge developing agrivoltaic projects. **We would like you to compare the relative importance of the factor on the left with the factor on the right by putting "X" in one box per pair based on the given scale below.**

The importance of the factor on the left side increases relative to the factor on the right as the scale moves to the left from 3 to 9					1 = Both are equally important	The importance of the factor on the right side increases relative to the factor on the left as the scale moves to the right from 3 to 9				
1 = Both are equally important, 3 = Somewhat more important, 5 = Much more important, 7 = Extremely more important, 9 = Absolutely more important										
	9	**7**	**5**	**3**	**1**	**3**	**5**	**7**	**9**	
Agrivoltaics require more land than solar alone										Limited adoption of agrivoltaics by other solar developers
Agrivoltaics require more land than solar alone										Difficulty of coordinating operations with farmers/landowners
Agrivoltaics require more land than solar alone										Higher risk and liability during project development, operation, and management
Limited adoption of agrivoltaics by other solar developers										Difficulty of coordinating operations with farmers/landowners
Limited adoption of agrivoltaics by other solar developers										Higher risk and liability during project development, operation, and management
Difficulty of coordinating operations with farmers/landowners										Higher risk and liability during project development, operation, and management

OPPORTUNITIES

Opportunities represent ***positive factors external*** to solar companies that motivate the solar industry to develop agrivoltaic projects. **We would like you to compare the relative importance of the factor on the left with the factor on the right by putting "X" in one box per pair based on the given scale below.**

The importance of the factor on the left side increases relative to the factor on the right as the scale moves to the left from 3 to 9					1 = Both are equally important	The importance of the factor on the right side increases relative to the factor on the left as the scale moves to the right from 3 to 9				
1 = Both are equally important, 3 = Somewhat more important, 5 = Much more important, 7 = Extremely more important, 9 = Absolutely more important										
	9	**7**	**5**	**3**	**1**	**3**	**5**	**7**	**9**	
Expanding solar into rural farmlands										Reducing vegetation management and operational cost
Expanding solar into rural farmlands										Reducing community opposition to solar
Expanding solar into rural farmlands										Gaining reputation as agrivoltaics leader
Reducing vegetation management and operational cost										Reducing community opposition to solar
Reducing vegetation management and operational cost										Gaining reputation as agrivoltaics leader
Reducing community opposition to solar										Gaining reputation as agrivoltaics leader

THREATS

Threats represent ***limiting factors external*** to solar companies that challenge developing agrivoltaic projects. **We would like you to compare the relative importance of the factor on the left with the factor on the right by putting "X" in one box per pair based on the given scale below.**

The importance of the factor on the left side increases relative to the factor on the right as the scale moves to the left from 3 to 9					1 = Both are equally important	The importance of the factor on the right side increases relative to the factor on the left as the scale moves to the right from 3 to 9				
1 = Both are equally important, 3 = Somewhat more important, 5 = Much more important, 7 = Extremely more important, 9 = Absolutely more important										
	9	**7**	**5**	**3**	**1**	**3**	**5**	**7**	**9**	
Lack of investment funds for agrivoltaics (e.g., loan, microfinance)										Commercial risk associated with novel technology
Lack of investment funds for agrivoltaics (e.g., loan, microfinance)										Lack of regulatory assurances to support agrivoltaics
Lack of investment funds for agrivoltaics (e.g., loan, microfinance)										Lack of policy incentives for agrivoltaics (e.g., tax credits)
Commercial risk associated with novel technology										Lack of regulatory assurances to support agrivoltaics
Commercial risk associated with novel technology										Lack of policy incentives for agrivoltaics (e.g., tax credits)
Lack of regulatory assurances to support agrivoltaics										Lack of policy incentives for agrivoltaics (e.g., tax credits)

Overall Comparison of Strengths, Weakness, Opportunities, and Threats

Finally, **compare the overall importance of strengths, weaknesses, opportunities, and threats that may affect the development of agrivoltaics projects.** We would like you to compare the relative importance of the factors on the left with those on the right by putting “X” in one box per pair based on the given scale below.

The importance of the factor on the left side increases relative to the factor on the right as the scale moves to the left from 3 to 9					1 = Both are equally important	The importance of the factor on the right side increases relative to the factor on the left as the scale moves to the right from 3 to 9				
1 = Both are equally important, 3 = Somewhat more important, 5 = Much more important, 7 = Extremely more important, 9 = Absolutely more important										
	9	**7**	**5**	**3**	**1**	**3**	**5**	**7**	**9**	
Internal positive motivating factors to develop agrivoltaic projects										*Internal negative* challenges to develop agrivoltaic projects
Internal positive motivating factors to develop agrivoltaic projects										*External positive* factors motivating to develop agrivoltaic projects
Internal positive motivating factors to develop agrivoltaics projects										*External negative* challenges to develop agrivoltaic projects
Internal negative challenges to develop agrivoltaic projects										*External positive* factors motivating to develop agrivoltaic projects
Internal negative challenges to develop agrivoltaics projects										*External negative* challenges to develop agrivoltaic projects
External positive factors motivating factors to develop agrivoltaics projects										*External negative* challenges to develop agrivoltaics projects

9. If you would like to provide additional feedback, please do so in the box below:

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We appreciate your participation in this research.

You may now send the survey to us in the attached pre-paid and self-addressed envelope.

If you misplaced the pre-paid and self-addressed envelope, please mail the survey to us at:

[Redacted Name and Mailing Address of a Researcher]

For further contact

[Redacted Name and Email IDs]