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Integrating solar energy with agriculture: Industry perspectives on the market, community, and socio-political dimensions of agrivoltaics

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ABSTRACT

Large-scale development of solar-generated electricity is hindered in some regions of the U.S. by land use competition and localized social resistance. One approach to alleviate these coupled challenges is agrivoltaics: the strategic co-location of solar photovoltaics and agriculture. To explore the opportunities and barriers for agrivoltaics, in-depth interviews with solar industry professionals were conducted and findings suggest that the potential for an agrivoltaic project to retain agricultural interests and consequently increase local support for development is the most significant opportunity of dual use solar. Capable of increasing community acceptance, participants expect agrivoltaics to play an important role in future solar endeavors, especially in places where development may be perceived as a threat to agricultural interests. The results further reveal the interconnections among the various dimensions of social acceptance and suggest that the growth of agrivoltaics is contingent on market adoption of the technology through community acceptance and supportive local regulatory environments. As solar photovoltaic systems transcend niche applications to become larger and more prevalent, the dimensions of social acceptance, including the opportunities and barriers associated with each dimension, can help inform decision making to enhance the growth of agrivoltaics and thus photovoltaic development. The findings can help land use planners, solar developers, and municipal governments make informed decisions that strategically and meaningfully integrate agriculture and solar, and in turn provide multiple benefits including the retention of agricultural land, local economic development, and broad adoption of solar energy technologies.

1. Introduction

Despite the mature and promising potential for solar photovoltaic (PV) technology to retrench global reliance on fossil fuels, large-scale PV development is experiencing complex challenges, including land use conflict [1–3] and — as the scale of solar has increased — social resistance, which has previously been more commonly associated with large-scale wind farms [4–6]. Growth in large-scale PV development can create land use disputes, especially in instances of competition between land for agriculture versus energy production [1,7,8]. This history and growing concern over land use highlights the challenge of meeting the soaring demands for solar power while conserving rural and agricultural lands [9]. It is posited that the impact of solar development on land will be diminished by siting PV in a manner that is compatible with multiple uses [10], suggesting changes in conventional practices will be necessary.

Agrivoltaics, the co-development of land for both agriculture and PV, is an innovative and increasingly popular approach to solar development [11–14]. This deliberate co-location of agriculture and PV is intended to alleviate land use competition [2] and boost revenues for landowners [15], among other benefits. Numerous empirical studies have investigated the technical viability of agrivoltaic systems, examining PV with plant cultivation [11,16–22], aquaponics [23], and livestock production [24–28]. Overall, agrivoltaic systems have been demonstrated as a technically and economically practical use of agricultural land, capable of overcoming the dominant separation of food and energy production and increasing land productivity by 35–73% [11].

This work is part of a larger study of agrivoltaic technology [27] that involves technical and social research as well as life cycle assessment

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(DE-EE0008990). Interviews were conducted with both solar industry professionals and agricultural industry professionals [30]. Interviews with agricultural professionals suggests that the effective diffusion of the agrivoltaic innovation is strongly related to the acceptance of farmers [30], which further emphasizes the need to study the technology within a social context to identify and address relevant barriers. Analysis of both interview datasets was conducted inductively, meaning that a conceptual framework for making sense of the data was not applied prior to empirical examination of the interview transcripts. Inductive coding revealed that within the broad category of opportunities and barriers, solar industry professionals and agricultural industry professionals are focused on different considerations; agricultural industry professionals see agrivoltaics as an innovative technology and the diffusion of this innovation was discussed based on dimensions highlighted in the diffusion of innovations framework [30]. Solar industry professionals, in contrast, were also asked about opportunities and barriers, but their responses focused on the potential for agrivoltaics to improve the social acceptance of solar technology. The value of taking an inductive approach to this research is the opportunity it provides to reveal this divergence, the implications of which are considered in the discussion.

The specific intent of this study was to draw insight about solar development from participant experience, and responses indicate that the most considerable opportunities and barriers center on social acceptance and public perception issues. Perspectives about the opportunities and barriers to agrivoltaic development were captured via interviews with solar industry professionals, and inductive analysis revealed that interviewees were most focused on opportunities and barriers that correspond with Wüstenhagen et al.'s [4] three dimensions of social acceptance: market, community, and socio-political factors. The social acceptance of renewable energy is shaped by a complex interplay among market, community, and socio-political factors [4]. While this framework is constructive for understanding the varying dimensions of social acceptance, Devine-Wright et al. [31] assert that it is weak in terms of the relationships between dimensions, suggesting that further research should apply a holistic approach for discerning the interdependence among factors shaping social acceptance of renewable energy. The purpose of this study is therefore to explore the perceptions of industry professionals in the U.S. and consider the implications of the identified opportunities and barriers from a social science perspective.

While the participants of this study discuss this technology specifically in the context of their experience, which is primarily with grazing and pollinator applications, the results are relevant to agrivoltaics more broadly. By grounding to relevant solar industry professionals' experience navigating solar development, the insights drawn from this study speak to the opportunities and barriers of various agrivoltaic applications through analytic generalization [29]. The findings can help land use planners, solar developers, and municipal governments make informed decisions that strategically and meaningfully integrate agriculture and solar and in turn provide multiple benefits including the retention of agricultural land, local economic development, and broad adoption of solar energy technologies.

2. Literature review

Social acceptance of renewable energy (RE) infrastructure plays a critical role in the furtherance of the RE transition and social science research helps to better understand the factors that impact acceptance and expansion of such technologies [4,6,31–33]. While many previous studies are focused on renewable sources of fuels and electricity including ethanol, wind, and hydro and are not specific to solar, they are nonetheless broadly applicable, emphasizing energy development as a social matter with technical components rather than a technical matter with social components. Wüstenhagen et al.'s [4] three-dimensional social acceptance framework moves beyond designations of people as simple supporters or opponents and recognizes that the acceptance of RE is a complex social response [34]. Although Wüstenhagen et al.'s [4] work is based on wind energy and renewables in general, the constructs developed are applied here to agrivoltaics because of the similarities between large tracts of agricultural land being appropriated for solar energy generation and large tracts of land appropriated for wind and other large-scale RE projects. As new energy technologies such as agrivoltaics transcend niche applications to become more prevalent, the dimensions of social acceptance, including the opportunities and barriers associated with each dimension and their interconnections, can help inform decision making to enhance the growth of agrivoltaic development.

Recent research maintains that the social dimensions of developing energy systems are perhaps the most critical, as previous endeavors in the U.S. reveal that the social component to development can ultimately determine the success of a solar project [3,32,35–40]. Bell et al. [41,42] describe a "paradoxical social gap" between high public support for wind energy but low success for concrete local developments, highlighting a discrepancy that is limiting the proliferation of RE. Public opinion surveys conducted by Carlisle et al. [37] confirm this social gap with regard to solar energy, finding strong American support for large-scale solar yet eminent opposition to local projects. The overall positive attitude towards solar has effectively (mis)led relevant actors to overlook social acceptance as an invaluable element of development [4], further widening the gap between project proposal and ultimate implementation. Because social acceptance is pivotal to energy transitions, this study reflects a proactive attempt to understand agrivoltaics from a solar industry professional's perspective to better understand the opportunities and barriers of agrivoltaic systems; the responses centered on themes related to social acceptance and public perceptions, therefore this paper places the findings from this research into the context of Wustenhagen's social acceptance framework.

2.1. Market acceptance

The market dimension of RE acceptance includes market adoption [43] and the acceptance of a technology by consumers, investors, and firms [4]. Devine-Wright et al. [31] explain that the proliferation of RE innovations depends on how the technology fits into markets and stimulates investment and that issues regarding business and revenue models, including siting decisions, play a pivotal role in acceptance by different market players. Wüstenhagen et al. [4] assert that acceptance can be expressed as investment. From an investor's perspective, the reliability of a RE technology is paramount for its implementation. However, the lack of reliable information for stakeholders is understood to be the most typical barrier to market acceptance [44]. To investigate conditions that promote market acceptance, three factors are particularly relevant: competitive installation/production costs; mechanisms for information and feedback; and access to financing [32].

2.2. Community acceptance

Building on the significance of the local context of RE, research has turned towards addressing community-level resistance and siting conflict [3]. Many studies have shown that successful implementation of RE systems necessitates sensitivity to local community preferences and values [38,45,46]. More than 25 years ago, Walker warned that the pursuit of RE expansion should not happen at the expense of local impacts, stressing the importance of "locally appropriate" projects [47]. Research focused on the community dimension of RE finds that support from local populations is arguably the most critical component to the actualization of projects [48]. It turns out the classic NIMBY (not-in-my-backyard) perspective does not adequately characterize the disconnect between high levels of general support for RE and localized opposition. Studies have found that place-based elements impose a major influence on community perceptions and attitudes [48,49]. Thus, considering and accommodating community preferences and values is consequential for gaining social acceptance of a localized solar project.

Yet there may be other community acceptance drivers, looking at wind energy as an example. Bergmann et al. examined preferences for RE (specifically wind and hydro) among rural and urban residents and found that rural residents perceive RE to be threatening to current economic interests associated with natural amenity tourism [50]. Mulvaney et al. [51], however, found that rural residents perceive wind turbines as an opportunity to protect their farmland from other land uses, thus preserving rural identity. Guerin [52] asserts that without support from rural landowners and farmers, large-scale PV will be severely limited and that the successful implementation of agrivoltaic systems lies in farmer acceptance. Because solar projects that represent local communities are expected to have higher levels of acceptance [44], it will be important that the design and scale of agrivoltaic systems align with rural identity and interests.

2.2.1. Stakeholder engagement

Within the domain of community acceptance, stakeholder engagement and participatory decision making are well recognized strategies that contribute to higher levels of acceptance and successful RE developments [6,38,53]. Soliciting participation from the public effectively ensures local voices are heard, considered, and incorporated into a project [54], giving developers direct opportunity to reflect local priorities in a RE development. Upholding community values and goals, both better understood and addressed through public participation, is thus invaluable and strategic, as a system that is designed inclusively lends itself to local acceptance rather than resistance [38]. Chrislip & Larson explain that failure to include all affected stakeholders in the development process impacts both the legitimacy and viability of a project [55]. Consideration of all involved stakeholders through participatory energy planning can contribute to the design of a project that generates localized benefits: the monetary gains from a RE project remain in a community [56] and a sense of cohesion and pride tends to mature amongst residents [57]. Simpson suggests that meaningful engagement with local communities and relevant stakeholders has the capability to build trust in both RE and developers [44]; trust is also considered a prerequisite to project support. Therefore, a democratic and collaborative approach to development may be a key consideration for the social acceptance of agrivoltaics.

2.3. Socio-Political acceptance

The socio-political dimension of acceptance encompasses policymakers and key stakeholders. Wüstenhagen et al. [4] assert that this may be the predominant dimension, given that policies and regulations create an institutional framework for RE, which effectively shapes market and community acceptance. Research on the socio-political acceptance of RE has sought to understand this dimension by using both public opinion research aimed at measuring factors that influence support for RE [37,58,59] and investigation of government policies and incentives [60,61]. According to Simpson [43], policies that provision financial incentives generate greater social acceptance of solar, especially if the hosting communities benefit the most. Implementation of solar is ultimately a local political decision as municipal governments and zoning boards include members of the relevant community and provide a forum to incorporate the views of the public, therefore an awareness that solar projects operate within a local policy context is necessary for successful development [38]. Application of these research findings to the emerging agrivoltaic concept requires investigating how policy measures, public participation models, and social institutions can help stimulate social acceptance of such developments.

3. Research methodology

In-depth, semi-structured interviews with U.S. solar industry professionals were selected as the most suitable methodology to explore perceptions regarding the opportunities and barriers to agrivoltaics. Interview methods establish validity of measurement by soliciting credible responses from participants and providing a means to gather nuanced descriptions surrounding the phenomenon under study [62–64]. While appropriate for the purpose of this study, interview methodology as a data collection technique inherently has limitations. Perhaps of most relevance is social desirability bias, which can be understood as the tendency of study participants to forego providing responses that truly reflect their feelings, choosing to answer in a way they perceive as "socially desirable" [65]. Additionally, interviews happened virtually rather than in-person, which may have altered the interview environment, thus impacting the authentic flow of respondent's replies. Despite these limitations, this research adhered to established techniques for data collection and analysis, rendering the data as objective and systematic as possible [66].

Table 1
Interview Participant Characteristics.

Profession	Geographic Region	Gender
Solar Developer: 8 Performance Engineer: 3 Policy Expert: 3	Northeast: 5 Southeast: 3 Midwest: 4 West: 2	Male: 11 Female: 3

This study specifically engaged solar industry professionals, primarily developers, as they have firsthand knowledge and direct experience with solar development and the factors that shape the success or hinder their projects. Because the majority of interviewees are experts in solar energy development, their responses focused on the components of agrivoltaics associated with solar energy rather than focusing on specific dimensions associated with the agricultural component of such projects. These key informants were selected to share their relevant experience and speak specifically to the dynamics involved in solar energy development and the opportunities and barriers involved in integrating agricultural production with solar energy, rather than directly representing the opinions of the general public.

Fourteen interviews were conducted with people who self-identified as solar developers, solar performance engineers, and energy policy experts, 10 of whom had some experience with agrivoltaics, with most of that experience involving passive grazing or pollinator-friendly planting systems. Recruited through existing research networks, participants were engaged via email invitation that included a brief introduction to the agrivoltaic concept and an overview of the study. The interviews lasted from 30 to 90 minutes, occurring virtually through video conference. Data collection was completed between February and April 2020 and continued until saturation was reached. As is customary among researchers applying grounded theory analysis techniques, data saturation is sought as the point where no additional new information is extracted from participants and novel patterns in the data stabilize [67,68].

Theoretical and snowball sampling methods were purposefully used to select study participants, as these sampling strategies are deliberate in capturing a sample with certain characteristics [67–70]. Theoretical sampling is a non-probability technique used to select participants based on specific characteristics that align with the research purpose [67,68], whereas snowball sampling is an accumulation process that builds a sample based on referrals from study participants to other acquaintances who have the potential to contribute to the research inquiry [70]. For this study, the aim was to interview solar professionals to achieve logical representation of a wide range of diverse and relevant perceptions related to agrivoltaics. These sampling strategies captured a heterogeneous sample of participants representing different professions, geographic locations, and gender (See Table 1).

The geographic regions in Table 1 are defined in accordance with standard regional classifications in the U.S., in which a region is established based on its geographic position [71]. Of the five regions commonly considered in the U.S. (West, Southwest, Midwest, Southeast, Northeast), this sample includes participants from the West, Midwest, Southeast, and Northeast regions. A map of the U.S. geographic regions is presented in the Appendix (Fig. 1), sourced from National Geographic Society [71]. Further, the participant classification of "policy experts" is inclusive of a University extension agent based on their relevant experience.

By use of semi-structured interview protocol and grounded theory methodology, data collection proceeded concurrently with data analysis [66,72]. Striving to understand the social dimensions of agrivoltaics, interview questions were loosely organized around three themes: (1) solar development and important factors that stimulate or challenge a project; (2) experience with and perceptions of agrivoltaics, including its benefits, opportunities, barriers, and risks; (3) potential for growth of solar energy through agrivoltaics. As is standard in practice of utilizing interview methods and a grounded theory approach [66], responses derived from the first interviews conducted then informed the evolution of subsequent questions, which naturally progressed over time to address specific factors involved in agrivoltaic development. The baseline interview protocol (see Appendix) was used consistently, but additional questions and prompts matured based on previous interviews.

Driven by the flexible and durable approach of the grounded theory method, interviews were analyzed on a line-by-line basis to explore nuances of meaning [66]. A series of coding combined with analytic induction and constant comparative analysis were used to analyze data for insight into patterns, processes, and connections. Analytic induction is the procedure of identifying patterns in qualitative data by establishment of themes and categories, followed by progressive distillation of those themes and categories by repeated comparison against new observations [73].

Research received approval from Michigan Technological University's Institutional Human Subjects Review Board prior to initiation. Interview participants provided consent for the recording of conversations, which was followed by manual transcription and input into the qualitative data analysis program *NVivo 12 Pro* for analysis [74]. Data has been anonymized for the protection of participant's privacy. By virtue of interview methodology, these findings do not lend themselves to statistical analysis or generalization. Given the nature of the sample, findings are presented descriptively to avoid suggesting that they are directly generalizable in the sense that a random and representative sample may be. However, only themes raised by the majority of participants are discussed as findings, revealing the core themes most commonly advanced by interviewees (see Table 2).

4. Findings: Understanding opportunities & barriers to agrivoltaics

The findings are organized below according to each dimension of social acceptance: market, community, and socio-political acceptance. Exact quotations, indicated in italics, are provided along with analysis. The results, which build directly on previous research on the social acceptance of renewable energy, offer the first insights into the social acceptance of agrivoltaics and identify opportunities, such as public perceptions, as critical. Section 5 provides a discussion of the implications of these results, including an overview of key findings and recommendations.

4.1. Market acceptance

Participants spoke directly to the market challenges associated with agrivoltaics. Themes related to development including complexity, risk, safety, liability, economic profitability, and non-monetary benefits surfaced frequently during interviews, providing insight into the most relevant market opportunities and barriers to agrivoltaics as perceived by industry experts. Based on the magnitude and frequency of market factors raised by participants, this dimension of social acceptance is considered most challenging in the context of agrivoltaic development.

4.1.1. Complexity, Risk, Safety, liability

Solar industry professionals in this study view agrivoltaic projects as complex and requiring extra effort to actualize, including added layers of intricacy in system design and increased coordination with stakeholders. Concerns of complexity range from the technical details of accommodating a dual use under the solar array, the impact, of say, non-optimal tilt angles on electrical production, and other considerations such as balancing stakeholder interests, all of which encumber project development, as stated by one developer and one engineer:

> You add something, it's more cost, more maintenance, more complexity, more work, more training, more people, more stuff. It's harder to pull it off.
> The problem is you have to do all of the things you normally have to do to get a solar project, and then you burden yourself on top of it by having to do a mixed-use site.

Participants detailed the elaborate development process for new solar installations. Adding another layer of complexity is perceived as "more headache than it's worth," as one developer expressed, making pursuit of agrivoltaics unattractive from this perspective, and potentially financially burdensome, presenting a barrier to market acceptance. Although the majority of participants (13 of 14) spoke of the commendable benefits of agrivoltaics, half of the interviewees said the extra effort needed for development is effectively a deterrent; one policy expert with experience in agrivoltaic development explained:

> The challenge there is trying to get people to want to pay the time and effort to now go through an added level of design. Now I've got to sit with [a farmer] and figure out what she needs so that my system accommodates her farming equipment, the crops she might want to grow. Developers, they already have enough layers, they don't need another layer, they don't need to be educated on something else.

Despite the barriers imposed on development associated with the perceived complexity of agrivoltaic installations, participants reveal a potential trade-off between complexity and coordination. Expending substantial effort and resource to manage the logistics of a dual use project and involve farmers in the planning stages may be key to the success of agrivoltaic projects, as suggested by three different developers:

> On the operational side it creates complexity, but on the development [side] it helps you build partnerships, it helps you get community approval, it helps you benefit the local environment with pollinators or animals or whatever they're doing to help the land.
>
> If it is a local partnership opportunity, then it puts a different personality on the project rather than being a nuts and bolts thing. It's actually something that could help the local community, or at least members of the local community.
>
> It probably slightly hurts your operating expenses due to the complexity and not really making any money on it, but it helped you build the project.

Speaking from experience, many participants perceived the value of stakeholder engagement as potentially greater than the added burden of development complexity. Almost 80% (11/14) of participants discussed that actualizing the benefits of agrivoltaic systems has clear trade-offs: building relationships and gaining support for solar come at the price of time and effort. The importance of community relations as expressed by participants is further discussed in subsection 4.2.

Further, participants also raised concerns around risk, safety, and liability, which represent notable market barriers to the realization of agrivoltaic projects. Both developers and engineers were thoughtful about the logistics of hosting a farmer on an electrical site. Considerations of designing an agrivoltaic site that is both safe and agreeable is explained by one developer who has experience with dual-use projects:

> A big hurdle too is just having that third-party liability insurance, that is huge from both a safety and a legal perspective on the developer side. Because any one person or thing that's on your site, not that an animal would have insurance, but a farmer or somebody that is on site, they have to have a certain amount of coverage to protect themselves and the developer from any type of safety risks, hazards, things like that.

In the face of safety hazards, risk, and potential liabilities, some participants are skeptical about adding an agricultural function to a conventional solar site, but two other developers point out that deliberate coordination in project design could address these concerns:

> We would just want to work something out where we both have proper access, proper liability coverage, in case his animals do any damage, in case he gets electrocuted.
> As long as there is some agreement in place between us and the farmer about not stepping on each other's toes, then I don't really see any problems with it.

While challenges associated with risk, safety, and liability are apparent to participants, those with experience in agrivoltaic development suggest that due diligence through collaboration with involved parties can overcome them. In short, the significant barriers to market acceptance of the technology as explained by participants are related to complexity and risk. This finding illustrates how different market players perceive the reliability of the technology, suggesting that market acceptance of agrivoltaics is influenced by anticipated costs and risks.

4.1.2. Economic profitability

Participants lamented the constraint economics pose on project fulfillment, explaining that a development has to "pencil financially" in order to be realized. Some participants expressed doubts that investors would finance an agrivoltaic project because dual use has the potential to compound risks and uncertainties. Similarly, participants stated concerns about the costs associated with the increased coordination required to actualize a dual-revenue stream. Skepticism that an agrivoltaic project would generate additional revenue for solar companies was recurrent, but participants explained that savings could be of greater utility than profit; two different developers without experience in agrivoltaic described a potential economic benefit of agrivoltaics involving animal grazing:

> I think at the bare minimum it would need to either offset or displace whatever the current vegetation management program costs are. I don't think I really expect them to necessarily make money off of it, but if it could eliminate or reduce some cost, that would be helpful. On the other hand, you have these animals who need to be fed- they come in and in a matter of weeks they can completely manage that vegetation. So, it's kind of a win–win for the farmers and the owners of the powerplant. It offloads the need to manage that vegetation.

Doubtful about sizable earnings but interested in potential savings, participants postulated that synergies derived from grazing animals underneath the panels could save on operations & maintenance (O&M) costs. While agrivoltaics aren't perceived by participants to provide an ensured revenue generation stream for solar companies, they are widely considered by participants to be a money-saver, highlighting an opportunity for dual use development to be a benefit rather than a burden. One developer without experience in agrivoltaic projects explained that the benefits could be manifold:

> I think financially it would be huge for everybody. The investor wouldn't care as long as they're saving. I don't think the solar system owner would care as long as it doesn't negatively affect them- they have something in writing to cover themselves for liability and injuries and insurance, and their O&M is significantly reduced. The farmer is more profitable and/or is able to sell their meat for less. And its, you know, free range, natural, grass fed, outdoor meat.

One policy expert and one developer both with experience in dual use systems reflect on the opportunity for developers to directly benefit financially from an agrivoltaic project:

> We are seeing sheep farmers creating new value-added business. They just rent their sheep, they bring them there and leave them there and do a solar project in two to three weeks. And I think that's something that is probably another level to this business that a lot of the developers were hoping could be a creative way to overcome that added maintenance that goes into these projects.

> If you have an additional revenue stream that is associated with that solar plant, I think it potentially can actually benefit the solar industry because it can help absorb some of the incremental costs and provide the developer an incremental revenue stream and a motivation to do solar.

While participants explained that economic constraints are eminent in solar development and that they do not expect large economic returns from agrivoltaic ventures, they also anticipate that the opportunities that such developments could provide are beyond the bottom line. These findings suggest that the significant benefits related to agrivoltaic development transcend increased profit, as further discussed below. Issues related to revenue models and investment in solar development have been identified by these participants, highlight both economic uncertainties and opportunities as important to the market acceptance of agrivoltaics.

4.1.3. Non-Monetary benefits

Generating an added revenue stream for farmers surfaced as a primary rationale for undertaking an agrivoltaic development. This indicates the importance of the market dimension of agrivoltaics, especially because participants presume prioritizing increased revenue for farmers may positively impact other dimensions of acceptance. Solar industry professionals exalted the idea of benefitting the agricultural community as a chief reason for deploying a dual use system:

> I think the biggest reason for us wanting to do this was trying to give farms another option. Trying to tell them, "Look, you got prime land, why not try to do both?" We'd love to see farms contribute to our state environmental goals, greenhouse gas reduction, renewable energy goals. We'd love to see them be part of it and get a diverse income stream.

Considerations apart from revenue broadens the horizon of potential benefits agrivoltaic projects can produce. Some participants explained that the competitive edge resulting from local acceptance of a proposed development can be more valuable than increased revenue. Participants posited that forgoing economic optimum projects to better appease a community by retaining relevant agricultural interests may increase local acceptance of solar. For some developers, an agrivoltaic project may be worthwhile if it simply facilitates the development process, as indicated by discussions with three different developers with varying levels of experience with agrivoltaics:

> I don't imagine Mr. rabbit farmer really contributing a lot in terms of revenue to us, or even paying us. But I would hopefully, in this ideal world, like to see that if we put together this mixed-use partnership that helps both parties, that it helps us get through the development

> phase to build the project. I don't think we would be in this because we wanted to collect revenue from the farmer.
>
> If we are doing practical mixed use in agricultural areas, I would love to see some benefits in the development process, it would really incentivize this type of project. So, maybe they help you in the zoning approval process, or the interconnection process.
>
> It might be a good negotiating point for the solar developer when they're talking to the township about all this at a preliminary stage. They say "Hey, why don't you give me a break on the property taxes in return for co-locating or some kind of agrivoltaic situation."

This potential advantage in the development process was discussed by multiple participants as a "development selling-point." Agrivoltaics are regarded by participants as an approach to development that can leverage local interests strategically to cultivate advantageous community relations and build a positive reputation. Agrivoltaic development may generate branding and marketing benefits, as two policy experts expressed:

> There's also the perception and the branding and marketing benefit, right? So, "We are a solar developer that cares about land, farms, local food, supporting local economies, and supporting farmers, and we have a social mission." Again, I'm speaking for some theoretical developer that might want to be benefiting from the perception and the reality of supporting local economies and local farms and local production. I can imagine, I haven't seen this, but "Hey, we graze solar cows, we are making clean energy and we're making organic food" or whatever. So, a branding perspective from both the farmer's point of view, but probably also from the developers saying, "We are good local citizens, and we're doing good."
>
> Its more about competition. So increasingly, businesses, communities, towns, big energy buyers, they weren't just getting one proposal for solar, they were getting two or three or four, and they were like, "Well I narrowed it down to these two developers, they're both in roughly the same price range, which one do I like more?…Which one's going to make our company look better? Which one is going to make our brand look better?" So, it was a competition as people were looking to have additional environmental attributes that were fairly cheap.

Participants explained that changing the narrative about solar, to include the above benefits of agrivoltaics, may help shift public perceptions towards support for local developments. Existing at an important nexus between market and community dimensions of acceptance, agrivoltaic projects are viewed by participants as capable of producing savings on O&M costs, generating revenue for farmers, creating advantage in the development process, and establishing a positive brand reputation.

The market opportunities and barriers identified by participants illustrate that this dimension of acceptance is inclusive of the other two dimensions, being intricately tied to community relations and the local permitting process. The interlinkages among the dimensions of social acceptance are further detailed in subsections 4.2 and 4.3 and identify the most notable opportunities and barriers for agrivoltaic development as discussed by industry professionals.

4.2. *Community acceptance*

The potential for an agrivoltaic project to retain local community interests and consequently increase support for a proposed development emerged as the most significant opportunity solar industry experts perceive of co-locating solar and agriculture. Linked to the market dimension of acceptance, community acceptance legitimizes market player's development pursuits as participants explained that public perceptions towards solar are a pivotal determinant of project success. The market barriers identified by participants align with the community opportunities they discussed, in which issues associated with complexity and risk were suggested as addressable through meaningful community engagement and collaboration with stakeholders.

4.2.1. *Retaining agricultural interests*

The importance of local communities in determining the success of a solar development is a major theme in the interview results. Participants spoke from experience as they described instances in which their development pursuits were halted by localized community resistance, highlighting a key relationship between market success and public attitude towards solar. Postulating about the potential for an agrivoltaic project to increase social acceptance of solar, two different developers expressed:

> Some community benefits might be useful. So, it's not necessarily a monetary benefit, but this is where you could have something that's maybe less desirable from the community that a dual use might cause people to be a little more accepting. I can see that as a potential benefit.
>
> There's definitely a kind of public acceptance side of it that possibly the mixed-use can be a benefit for.

Multiple participants discussed the strategic appeal of leveraging an agrivoltaic project to preserve the agricultural function of land, aiming to uphold local interests in order for a solar system to be realized in that community:

> These are towns [where] really farming is their pride and joy, and I think they feel like, "Hey, we've been seeing these things go into the ground and cover it up, if this is something that can actually keep agriculture alive and well, let's give it a try."
>
> You're going to get at least some more cooperation from people who really want to see their farm survive, and they realize that a system like this can provide them with a diverse income, not just for agriculture but for the dollars that can be made on the electrical generation side.

By retaining local agricultural interests rather than threatening them, participants foresee agrivoltaic projects as being in a critical position nested in local values and community acceptance. Representing a righteous way to change the narrative about solar development, two developers explain how agrivoltaics may better appeal to agricultural communities:

> By being able to come into that community and say, "Hey, we're not only doing the clean renewable energy portion of this, but we'd also like to provide a little bit more of an economic background and crop yield improvement."
>
> You need to tell the story in a better way, which is, "this is good for the farmer, this is good for you the consumer because we're making low-cost power, it's renewable and we're doing what we can to impact climate change."

By design, the objective of an agrivoltaic project is to generate both electricity and agricultural products on the same plot of land, which solar industry professionals perceive as an advantageous alternative to conventional development practice in agricultural communities. The ability to preserve local values in solar development by retaining the agricultural function of land through an agrivoltaic installation was identified by participants as the most notable opportunity. Capable of increasing community acceptance, participants expect agrivoltaics to play an important role in future solar endeavors, especially in places where development may be perceived as a threat to agricultural interest.

4.2.2. *Community relations*

Participants discussed a notable trade-off between the effort invested in community outreach and the payback in terms of enhanced community relations. The time and energy devoted to stakeholder engagement can have potentially huge returns, as one developer with experience in dual use development explains:

> Just having that support and making sure that you're making those local connections at the community level is- I cannot harp on how crucial that is because without the local buy-in and approval your project is going nowhere.
>
> If I were to show up at a town hall meeting trying to sell this idea of having a dual use system in that community, it's going to be a lot more believable coming from somebody from that town that is supportive of it, or a third liaison that is an expert in agriculture or whatever it may be. Rather than myself, who no matter how much background and expertise I have in it and drive to make it happen, I'm still the developer in the room. So, getting those third parties involved is really crucial because they are seen, and they are the true experts.

Solar professionals spoke of the absolute importance of community relations in development, explaining that local partnership opportunities are invaluable and potentially accretive to the long-term growth of the solar industry. One policy expert suggests this importance:

> [We are] trying to always be candid with helping solar developers realize that the biggest benefit is that they as developers will have a local partner.

Participants commonly identified community engagement as a worthwhile investment of their resources during the development phase. By stimulating local relationships founded upon preservation of agricultural land, participants see agrivoltaic projects as an opportunity to meaningfully engage communities and uphold their values. While increasing complexity during the design phase, deliberate community and stakeholder engagement may be important element of agrivoltaic development, as one policy expert explains:

> If you have a farmer who's got to work under these panels on a day-to-day basis, then you really need to be thoughtful and invest a lot of time upfront on thinking about how that's going to work and how the farmer will continue to be able to farm at some level, while your panels are making power.

Despite the increased effort needed to foster worthwhile community relations, participants understand from experience the importance of local partnership in solar development. While the complexity may represent an added barrier, the opportunity for enhanced relationships was identified by participants an important part of agrivoltaic development that may be consequential in community acceptance.

For the case of agrivoltaics, participants of this study revealed that community acceptance is fundamental to successful development. Existing at a nexus between market and socio-political dimensions of social acceptance, the community dimension of agrivoltaic development was identified as the critical link between market adoption of the technology and favorable local regulatory environments. By purposefully retaining local agricultural interests in project development, participants see the potential for agrivoltaics to increase community acceptance of solar as the greatest opportunity.

4.3. Socio-Political acceptance

In the context of solar development, local regulatory environment was the aspect of socio-political acceptance most identified by participants. Drawing upon the significance of community acceptance, participants described how public attitude and the localized policies that have implications on solar projects are linked. Participants illustrated how community acceptance implies the existence of local zoning bylaws that are favorable of solar development, indicating that socio-political acceptance is embedded within the community dimension of social acceptance of agrivoltaics. Absent of supportive local policy, participants expect agrivoltaic development to encounter challenges and therefore frequently referred to the importance of gaining community acceptance and establishing beneficial partnerships. Speaking of the consequence of policy on solar development, developers and policy experts explained:

> We just do not have the environment right now at the regulatory state level that allows that type of development.
>
> They can stop a project, no matter how good it could be, just being local. Local rule is big in our state, and we have cities and towns, after their first experience, some people in the towns are strong enough politically to now write by-laws that say, "No more large-scale projects, you can't do anything over 100 kW, that's it, we're done, we're tired of seeing this land get covered up with solar panels."
>
> There definitely is a community element to it. Because your neighborhood and your community, both in the local and state level, have a lot of sway in the process. They can shut down your zoning permitting, they can shut down your building permitting.

As the policies that are impeding solar on agricultural land are a product of past community decisions and reflect local values, many participants asserted that engaging communities in project development can positively influence attitudes and regulatory environments to accommodate, rather than restrict, solar. Participants speculated that agrivoltaics present an opportunity to reinvigorate local policy to be more accepting of solar, as agricultural interests are deliberately upheld rather than threatened in dual use development. Giving a project "personality," as articulated by one solar developer, can provide a project that would otherwise be met with regulatory hurdles, support from local communities.

Participants discussed how communities may strategically use agrivoltaic systems to allow for solar development while simultaneously preserving agricultural land. For communities that want to increase their solar generating capacity yet strongly value their arable land, different policy experts identified an opportunity for agrivoltaic installations to be leveraged as a sort of development stipulation:

> Counties have ordinances and they say, "Well we have X amount of prime farmland in our county and so we want that land use to be beneficial, and so we will approve your solar project, but we want it to be pollinator friendly."
>
> Is it more just that a community wants both of these things? They want the solar and they want to have an opportunity to do some local farming or gardening- and placing the two in the same place makes it possible for them to do both. It certainly seems feasible.
>
> When you start to introduce things like dual use and try to bridge this really difficult niche with solar and agriculture industries, this whole dual use concept, it's typically a lot of times at the requests of that community.

Participants suggested that there may be an opportunity for agrivoltaic projects to become the prevailing norm of solar development in communities with conflicting land use interests. Through preservation of local agricultural interests, participants discussed that agrivoltaics may be an impetus to revise local policies that currently restrict or prevent solar development on agricultural lands, given they meet conditions set forth by the community. Majority of solar professionals posited that the two-fold objective of agrivoltaic systems could considerably soften localized opposition to solar, therefore capable of stimulating the design of local policies that are intentionally supportive of solar development.

Participants communicated that the socio-political acceptance of agrivoltaics is directly related to local regulatory environments. More specifically, the socio-political factors of agrivoltaic development described by participants are tied to local zoning bylaws, identifying a barrier to be addressed to increase acceptance along this dimension. While predominantly discussed by participants as barriers to solar development, the identified socio-political factors reveal opportunity to leverage local interests in project design to increase community acceptance and consequently encourage supportive local policy for agrivoltaics.

5. Discussion: Social acceptance of agrivoltaics

This research adds to an existing literature on the social acceptance of renewable energy by cataloging what industry professionals perceive to be the market, community, and socio-political dimensions shaping the opportunities and barriers associated with agrivoltaics. Results indicate that alignment among all three dimensions of acceptance will determine successful adoption of agrivoltaics; community acceptance was identified as the critical link bridging market adoption and socio-political factors, as community support can lead to advocacy and implementation of socio-political conditions like favorable policies that promote profitable development. Findings also suggest that agrivoltaics are potentially accretive to the solar industry, possessing the capacity to shift public perceptions and local policy towards support for solar developments. Although concerned about developmental complexity, study participants expressed that the agrivoltaic innovation may be key in retaining agricultural interests, consequently fostering local acceptance. Interview findings also cast light on the barriers to agrivoltaic development and identify opportunities to harmonize land use for both energy and agricultural purposes.

While essential, research that focuses solely on the technical aspects of agrivoltaics will ultimately be constrained by social factors related to project implementation. This study emphasizes agrivoltaic development as a social matter with technical components rather than a technical matter with social components, providing new insight into opportunities and barriers beyond technical and economic dimensions. This research holistically explores the various dimensions of acceptance related to the emerging agrivoltaic innovation, exemplifying how the interconnections between them may be aligned to increase social acceptance and dual use solar development.

Table 2 below provides an overview of key findings and recommendations that emerged from interviews with 14 solar industry professionals. Each finding identifies opportunities for building the market, community, and socio-political framework needed to actualize agrivoltaics. These results are based primarily on solar industry professionals' perspectives and thus do not represent the opinions of the general public. The recommendations stated in Table 2 are aimed at a broad coalition of stakeholders, including solar developers, policy makers, municipal land use planners, and local governments interested in pursuing agrivoltaics. Table 3 (see Appendix) presents representative quotes around significant themes that surfaced during interviews. Themes are organized in descending order of relevance based on the data and are aligned with the three dimensions of social acceptance.

5.1. Market Acceptance: Motives for agrivoltaic development

Previous research regards agrivoltaics as an opportunity to establish a dual-revenue stream for involved parties [12], yet the participants in this study expressed disinterest in profit, which they perceived as negligible, and instead spoke of the benefits beyond finance. Participants generally agreed that agrivoltaic projects may stimulate community acceptance of solar, easing the development process, which is perceived as a motivator equal to added revenue. Put another way,

Table 2
Overview of key findings and recommendations.

Theme	Major Finding	Recommendation	Relevant Actors
Complexity	Agrivoltaic projects are considered complex and requiring extra effort to actualize, including added layers of intricacy in system design and increased coordination with stakeholders.	Offer financial incentive to solar companies pursuing agrivoltaics to ease the burden of increased developmental complexity.	- State government - Local government - Solar developer
Safety and liability	Safety hazards to people and livestock and potential for damage to electrical equipment is concerning to developers and investors.	Prior to commissioning, design a contract between involved stakeholders that protects against risk and establishes liability. Model contracts off established wind developments on farmland.	- Solar developer - Farmer - Third party insurer
Economic profitability	Solar developers can save on O&M costs by accommodating grazing animals; farmers can receive revenue from a contracted vegetative maintenance service.	Develop a mutually beneficial business model that supports both parties financially, drawing insight from existing agrivoltaic projects in the U.S.	- Solar developer - Farmer
Non-monetary benefits	Enhanced reputation, competitive advantage, and ease in the permitting process are potential opportunities for solar developers.	Pursue development in a manner that purposefully upholds local values to enhance marketability and attitudes towards solar.Provide solar companies an expedited permitting process if undertaking an agrivoltaic project.	- Solar developer - Local community - Local government
Community acceptance	Agrivoltaics can leverage local agricultural interests to elicit community support for development.	Prioritize local interests in project development by designing systems that are locally appropriate through incorporating existing agricultural practices.	- Solar developer - Local community - Farmer
Local partnerships	Agrivoltaic projects can strengthen community relations.	Invest resources in stakeholder engagement and pursue meaningful partnerships to improve the development process.	- Solar developer - Farmer - Local community
Policy	Local zoning ordinances can be used to support or restrict solar development, especially development on prime farmland.	Revise local bylaws to accommodate solar on farmland, including provisions for retaining the agricultural function of land in PV system development.Develop state zoning enabling laws that explicitly preempts local solar restrictions in favor of agrivoltaic development.	- Local government - State government - Policy makers

participants deem community relations as advantageous to project completion and suggest that there is value in, and motives for, agrivoltaic projects beyond economic returns.

The findings from this study suggest that the market dimension of agrivoltaic acceptance is the most relevant and complicated, being inclusive of community and socio-political factors and consequential for successful technology adoption among developers. From the perspective of participants, market opportunities of agrivoltaics are directly linked to benefits such as retaining local interest, establishing community partnerships, and ultimately increasing local acceptance of a development, suggesting that future research should focus further on this market dimension. Specifically, the value of agrivoltaic development needs to be investigated and quantified beyond simple economic rates of return, including its potential for job creation and investment in host communities [75].

5.2. Community Acceptance: Retaining local values

As demonstrated by Wolsink's [76] U-curve of local acceptance, the lowest levels of acceptance are observed during the siting phase of RE development. This insight implies that efforts to align projects with community values should be concentrated on the siting and planning phases of a solar project. Interviewees spoke about the siting phase as a particularly pivotal point in project development. In many cases, developers recalled instances where local resistance during the siting phase completely halted projects from moving beyond conversation to construction. Based on warnings from developers and previous research [38], stakeholder engagement during the siting phase is key for reducing conflict and should therefore be seen as requisite for successful agrivoltaic development.

Agrivoltaic projects necessitate sensitivity to local nuances, interests, and values. Increased focus on retaining local identity through stakeholder engagement in agrivoltaic development may be effective in achieving community acceptance. Literature that discusses the role of place-based identities and attachments in social acceptance of renewable energy [77] maintains that projects that represent local communities are expected to have higher levels of support. The findings of this study suggest that agrivoltaics are an opportunity to connect solar developers with farming communities in a way that is rooted in local values.

While this study demonstrates that its participants believe that local partnerships are significant to agrivoltaic acceptance, it simultaneously demonstrates that community outreach includes increased time and effort. Participants explained that actualizing the benefits of agrivoltaic systems has clear trade-offs. Relationships, a positive reputation, and ultimately community support for solar come at the price of time and effort, but the expense is considered worthwhile. Ultimately, the potential for agrivoltaics to increase local acceptance of solar will depend on the developer's ability to incorporate local interests in the project design.

Designing agrivoltaic projects that consider the production of energy and food as equally important can ensure that future food production capacity is maintained and may provide a tool for community engagement and community acceptance. By considering case studies in which agrivoltaic development has been successful versus cases in which it has failed, future research may support forthcoming agrivoltaic initiatives by identifying challenges across various contexts. Similarly, future research should examine case studies that exemplify how stakeholder engagement successfully improved the agrivoltaic development process so that the opportunities and challenges of participatory planning and procedural justice in dual use projects may be ascertained. Drawing from previous studies that investigate public perceptions of various energy technologies [35,36,46,50], future work on agrivoltaics could compare both public and stakeholder attitudes towards different types of agrivoltaic applications, such as crop versus livestock production.

5.3. Socio-Political Acceptance: Local regulatory environments

Prior research demonstrates the consequential role policy plays in solar development [78,79]. Policy can operate as either a barrier or an opportunity for agrivoltaics. Conversations with solar developers reveal that successful development is contingent on local regulatory environments, suggesting that policy exists at the nexus between local attitudes and project realization. In fact, a few solar developers explained that in response to unfavorable policy, they no longer pursue ground-mounted solar systems and are especially restricted from development on agricultural land. Policies that impede solar on agricultural land reflect local opposition to development but suggest an opportunity for agrivoltaics. This assertion is based both on insight from participants and from the nature of lawmaking in the U.S., specifically local level zoning. Many states [80] grant clear participation rights to citizens during the development of local land use laws and permit review process, in which the general public can express support or opposition for a proposed development and insist on specific outcomes. Given that local governments and zoning boards include members of the relevant community and provide a forum to incorporate the views of the public, citizen attitudes towards a development are considered critical with regard to the establishment of policies that shape the local regulatory environment around solar energy.

The role of policy in agrivoltaic development suggests the power of local regulation as an opportunity rather than a barrier if local stakeholders can appreciate the added value of dual-use solar. Interviewees noted minimized land impacts and preservation of farmland as commendable advantages that could alter perceptions about development. State and local governments interested in increasing solar generating capacity and harnessing dual use benefits should design financial incentives to explicitly encourage agrivoltaics as well as ease regulatory burdens for agrivoltaic deployments. Governments could, for example, ensure that all agrivoltaic systems within their jurisdiction continue to be zoned and taxed agriculturally, given they maintain the agricultural function of the land. Future work is needed to determine the impact of such tax policy on PV system economics. Similarly, a short tax holiday could be used as an incentive to deploy agrivoltaics and thus maintain local agricultural employment on the land. This may be particularly appropriate where additional capital costs are needed for agrivoltaics (e.g. extra fencing for pasture fed rabbit-based agrivoltaics). At the state or federal level, feed-in tariffs can be used by regulators to encourage agrivoltaic development by providing long-term investment security to solar developers that specifically pursue agricultural co-location. In addition, energy policy that centers on energy sovereignty may be beneficial to agrivoltaic deployment. This type of energy policy promotes community level decision making about the sources, scales, and forms of ownership that characterize the energy services system [81]. Agrivoltaics can represent a means for communities to obtain energy sovereignty and can be coupled with initiatives for energy sovereignty such as those policies that support community solar projects [82].

Future research on the socio-political dimension of agrivoltaics should include an investigation into policy mechanisms that could incentivize the development of dual use solar projects. To leverage the power of local ordinances in solar development, future work should explore the potential for policy to act as both an incentive and a restriction- allowing solar development on farmland, for example, only if it meets set standards for an agrivoltaic system. Future investigations of socio-political barriers to agrivoltaics should determine the diversity of challenges present in various regions of the U.S., identifying context-specific distinctions that can provide regionally relevant insight to actors interested in dual-use development, especially regarding state and local level policy variations. Moving forward, addressing the socio-political concerns of agrivoltaic development will require a discrete focus on localized energy policy that is targeted at restricting solar on farmland.

5.4. Implications for decision making

Taking an inductive approach to research means allowing the conceptual themes and argument to emerge from the empirical data rather that applying a framework to the analysis of those data. In this research, an inductive approach reveals that solar industry professionals are focused on how agrivoltaics can shift the social acceptance of solar energy development, providing “projects with personality” that local communities may be more likely to support as they generate multiple local benefits that align with community priorities. However, they also acknowledge the complexity of these projects, particularly the complexity of working and navigating regulatory regimes across two different sectors (energy and agriculture).

This complexity becomes especially salient in the grounded context of decision making for agrivoltaic development. The study presented here is part of a larger interdisciplinary, multi-method project, and other work associated with the larger project [30] suggests that agricultural industry professionals are thinking about very different issues regarding the opportunities and barriers associated with agrivoltaics. Perhaps understandably, they did not discuss how agrivoltaics could support solar development by promoting social acceptance. Rather, they raised concerns associated with the adoption and diffusion of technological innovations, such as market potential and ease of integration into existing land management regimes and farming practices. They also raised concerns about the desire for fair and just compensation and about the potential impacts on long-term land productivity.

The different opportunities and barriers raised by these two different groups of actors highlights the potential for complex interactions in agrivoltaics decision making. If actors come to the table with divergence in their motivations, their concerns, and what they view as the opportunities and barriers, it may be more difficult for them to work together and ensure that each group has their needs and priorities addressed. By revealing the divergence in these two groups, this larger study can help both groups of actors better understand the other so that they have a foundation for working together on agrivoltaic decision making.

6. Conclusion

To address global demands for both food and energy, the relationship between critical land uses must become complementary rather than competitive. Because social acceptance of renewable energy technology is pivotal to energy transitions, this study reflects a proactive attempt to understand agrivoltaics from a solar industry professional’s perspective to better understand the significant opportunities and barriers to development. This research suggests that agrivoltaics are potentially accretive to the solar industry, possessing the capacity to increase social acceptance of local solar developments. While the agrivoltaic concept is widely supported by the participants in this study, popularity of an emerging technology among industry experts may not indicate local level acceptance of a specific development. As new energy technologies such as agrivoltaics transcend niche applications to become more prevalent, localized resistance is to be anticipated and the dimensions of social acceptance, including the opportunities and barriers associated with each dimension, can help inform decision making to enhance the growth of agrivoltaic development.

This study found that solar industry professionals perceive the potential for an agrivoltaic project to retain agricultural interests and consequently increase local support for development as the most significant opportunity of dual use solar. This indicates that solar developers can play an active role in cultivating social acceptance of agrivoltaics through public engagement. The results further reveal the interconnections among the various dimensions of social acceptance and suggest that the growth of agrivoltaics is contingent on market adoption of the technology through community acceptance and supportive local regulatory environments. Ultimately, agrivoltaic projects present an innovative opportunity to preserve the agricultural function of land while increasing solar generating capacity. This potential to increase local acceptance of solar gives both developers and policymakers reason to design public participation models and policy measures that support agrivoltaic development. These findings can help land use planners, solar developers, and municipal governments make informed decisions that strategically integrate agriculture and solar, and in turn provide multiple benefits including the retention of agricultural land, local economic development, and broad adoption of solar energy technologies.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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7. Appendix.

Initial interview protocol as approved by IRB.

1. Please tell me about the solar development decision making process:
   a. How does the process start?
   b. How does the process proceed?
   c. Who is involved in the process?
   d. What are some of the most important factors that shape whether or not a project will be successful?
2. For solar developers only:
   a. At what scale do you develop?
   b. How do you take care of vegetation management?
   c. How much do you spend per year on vegetation management?
3. Can you tell me about your experiences or perceptions of mixed use solar development, where solar PV is sited in a way that is used for multiple purposes? (e.g. agrivoltaics)
   a. Do you have experience with this kind of development? (If so, please tell me about that experience)
   b. What are your perceptions of this kind of development?
   c. What do you think are the biggest opportunities for mixed use solar development?
   d. What do you think are the biggest barriers for mixed use solar development?
4. Are you familiar with solar farms hosting grazing animals?
   a. If so, what are your thoughts on this?
   b. What is needed to make this idea more attractive to you?
5. A recent study has shown substantial economic opportunity for rabbit agrivoltaics. The Department of Energy has sponsored this

Table 3
Significant themes and participant quotes.

Dimension	Theme	Barrier	Opportunity
Market (4.1)	Complexity	1. The nature of it right now, it is pretty complicated. We take on a lot of risk and complexity operating projects like this. 2. For me it's a complexity and a headache and I don't want to deal with it. 3. I think when you start to do mixed use projects you create a lot more complications. 4. We attempted to see if we could make that happen, but the sheep farmer requirements were- there was a lot of effort and costs involved to make that happen, so we weren't able to do that.	1. Adding another layer is just going to increase complications. But you know, if it is something the client wants, we don't really care. 2. We're kind of becoming more familiar and aware of having to add this into our daily process, especially if we're going to be doing more ground mounted systems.
	Economic profitability	1. The point of building solar right now is to drive the price down such that it's cheaper than fossil fuel, and you want to build more of it. So, to me, you want a big square site with nothing else on it and no complications and you want to drive the cost as low as possible to get it built. 2. We're not moving forward with agrivoltaics in that particular area due to multiple cost constraints. 3. There is some upfront capital, the first couple of years are upfront costs- you want to be able to know that those costs are going to die down with time and you'll be able to see some long-term savings from a vegetation management perspective. 4. Economics is first and foremost, because ultimately, you're not going to be able to get buy-in from all of the teams internally from the development side if it doesn't pencil financially.	1. 1. If we were to bring in somebody like that, we would probably not be looking for a share of revenue per se, but maybe a payment to help defray some of our own lease costs. 2. Farmers, particularly small farmers, are struggling in many areas. So, the attractiveness of another revenue stream, even if that means sacrificing some land to grow, they could potentially make more money off of the solar revenue than they could off of the broccoli or whatever. 3. I don't think we would be in this because we wanted to collect revenue from the farmer, like I don't want a portion of his revenue or profit. 4. The increase in revenue, that's huge. I think having those components- you have solar, which is going to save money as far as electricity rates or energy savings, and then you have an increased revenue maybe with the [livestock] as well. 5. The cost is really a wash and more and more it's about competition and it's about big players in the market that know how to do beautiful projects, and know how to promote them, and that's moving other companies. 6. Things like planting a different seed mix or grazing or using a different type of vegetation management, are kind of like a drop in the bucket in terms of overall project costs. But ultimately you want to be able to pencil that into your project to be able to see a long-term savings. 7. Watering the crops could be somehow combined with cleaning the solar arrays as part of the same process that makes the cost of doing the two less than if they were done individually or something. 8. We could show people that, "Hey this can be on a piece of land and we can grow a high value crop and bring a lease payment to the farmers. It's a double value to them and therefore, we should do more of this." 9. If this does work out, and we do have these sites and this is a cash positive crop like it could be, this could have a financial business portion of it.
	Operations & Maintenance	1. If that state naturally has very low vegetative maintenance average costs, like the cost to mow and herbicide and things like that are already super low, you're going to have a really tough time convincing an O&M provider that having animals on site is going to be cheaper and more cost effective because ultimately, unfortunately, it always comes down to cost. 2. So it's really finding a dual use that has little cost impact and little maintenance impact or somehow reduces maintenance 3. Many times, you're still paying just as much to have a farmer graze sheep as you are on just somebody using the mower. 4. 4. Sheep aren't always…they're not really interested in the weeds. They're interested in the grass. So, weeds still become a problem. You still need some kind of manual mechanical maintenance of sites, even when you do have grazing animals.	1. It should reduce with time, those vegetation management costs, because you're not going to have to go out there with mechanical mowers every so often. 2. 2. Most likely in any given scenario with whatever type of alternative vegetation management you're working with, the first couple of years are probably going to be a bit of a higher cost. And then those costs typically reduce with time once the upfront equipment and stuff it is covered. 3. When those O&M providers are having to travel a bunch, have higher costs, different sizes of sites, just the whole list factors, then that's where you're probably going to have a better chance of having some type of alternative vegetation management, A.K.A. an animal. 4. The fact that you could figure something out that can be a saving, you know, a $500 a month check to mow- that money could be spent on something else that puts money in somebody's pocket. 5. It would be less expense for grounds maintenance and hopefully some benefit to the farmer.
	Risk, Safety, Liability	1. Safety would be one of the potential barriers that whoever was going to use the site would be able to do so in a safe manner without getting hurt. 2. We definitely have looked into all that and tried to get our investors to consider those ideas and we have not been successful. Mostly for those liability reasons. 3. What I know is that today, there's no banker or insurance company that's going to ensure or finance a project where there's a combine driving around under solar panels. 4. Basically, the idea here is someone gets in there, damages the array or gets hurt because they've touched something- making this huge investment that folks acquired something that is now an issue.	1. We can provide information to the farmer about what is necessary to keep the solar panels safe, but also get information from him on what is necessary for [livestock] to kind of thrive in that environment. 2. If somebody were to propose some kind of co-use, it would have to have those things taken into consideration including security at the site and the integrity of the site. 3. I think if the system is designed electrically correct, it's grounded, I don't think you're going to see a lot of animals get electrocuted or shocked in any way. 4. I know that we have had talks about plants, and I could see our investors getting some comfort level with that.

(*continued on next page*)

Table 3 (*continued*)

Dimension	Theme	Barrier	Opportunity
		5. I just think there is too much potential for damage if you got big equipment going down those isles. 6. Safety would be a big concern for us as well as the high voltage that those projects operate at, making sure that people are safe. 7. If you want to do it with animals and livestock, you have to worry about them eating wires or getting into somewhere that could kill them, which is really bad for everyone.	
Community (4.2)	Community Acceptance	1. It's getting people to understand the exact purpose, that solar does not take land out of agricultural use. And it needs to be proven and shown that it does not, and it's a decent use of space.	1. Where I think it would be most helpful though, is in community acceptance. 2. I see agrivoltaics, the various streams, whether its growing vegetables or farm animals, as potentially accretive or helpful to the growth and acceptance of solar. I think it's positive. 3. I think this type of project or projects in general, whether it be pollinators or livestock, are really cool. I think they kind of reinvigorate what people want to see with renewable energy and kind of a green future.
	Community Resistance	1. We started getting calls from farms, from just local people- people don't want things in their backyard, as well- really concerned about our farmland being taken up by solar development. So, the food versus fuel argument, "we're losing valuable land." 2. If you're coming into an area that's really unfamiliar with these types of technologies, I think that it's going to increase pushback. 3. People were calling us saying, "What are you doing? You can't just let these developments just start taking food away and putting solar in!"	4. If you're in more of the rural area that has livestock, then yeah, I think it could probably reduce the pushback. 5. It really comes down to the developer. Do they want to be a good neighbor, or do they want to push the project through?
	Local interests and values	1. There have been instances where we want to develop on land they're using and that they valued, and they didn't want to see it. 2. Even if the farmer is totally on board and the developer is totally on board, the community gets to say, "this is not in keeping with our community goals."	1. If you are in an area, maybe that already has an existing livestock history, maybe it's better to kind of mix those uses together there. If there's other space, that maybe it requires more of the plants, flowers, the fauna, flora, et cetera…. that it might make more sense. I really just think it's a context dependent kind of thing. 2. Local expertise is a huge factor. If there's a farmer next door that has a flock of sheep, it's going to be pretty affordable and economic to have sheep graze the solar farm. If a state has an abundance of expertise in planting and establishing pollinator habitat, it'll be way more cost competitive compared to other states that don't have this expertise. 3. The general public, who might live adjacent to farms and know farmers and want to support farmers, they would certainly want to be involved in the vetting and design of any dual-use program.
	Development "selling-point"	1. We're going to grow from 300,000 acres to 3,000,000 acres in the next 10 years. And it's not going to be bare ground, it's not going to be turf grass, you know? 2. They are realizing, "Crap, I don't want to be the next Blockbuster," and Blockbuster is turf grass solar.	1. It was a good selling point because we sold the project and the competitor didn't. 2. I imagine a situation like this for a company like us doesn't help us at all in terms of revenue, it helps us in terms of the development. 3. That would be a great thing to be able to go to the communities and describe an offer in conjunction with the PV. 4. In those areas where there are mixed-use opportunities, I think maybe you present them with an opportunity to kill two birds with one stone, for lack of a better phrase. 5. . I think it is a great idea and it might be the only way for ground mount PV to survive or continue at least in some regions.
	Local Partnerships	1. We're not going to get to all of our climate action goals, especially state renewable energy portfolio goals and things like that, without some consensus and comradery between both the solar industry and agriculture industry. 2. The solar industry itself, are they interested and willing to work hand in-hand with farmers on what are more expensive almost across the board, and complex installations?	1. I think that's where the main benefit is, in kind of a partnership to help the development phase. 2. So as an electric utility, if we were to think about co-use, we would be open to it but we would probably not do it ourselves because it's not a core part of our business, so we would happily partner with somebody to do it on our site. 3. If you're partnering with somebody else that has more local roots…that might be a different story because the local story gets broken down there. 4. Really understanding the land that you're working with, and the community you're working with, and maybe the landowners you're working with, to kind of work what's best for them. And just getting a sense from them what the best use would be in conjunction with the solar. 5. When we go to develop a solar facility, we are there to provide clean energy to that community. And we work with that local community to get to know them, what their needs are, provide as much information as we can about renewable energy, specifically solar and what benefits that will provide to their community. And not only from a clean and renewable energy future, but also the economic benefits for their community.
Socio-Political (4.3)	Policy	1. Things related to land-use have started to change five years ago and now especially, the conditions and restrictions are much tighter. It is at the point where you cannot- there are ways- but it	1. It just keeps ramping itself up and to the point where we now actually have an incentive to put dual use in through a state solar program, which is the first time we are able to do that.

(*continued on next page*)

Table 3 (*continued*)

Dimension	Theme	Barrier	Opportunity
		is very difficult to put a large solar array on a parcel that is, has been, or currently is being used for agriculture purposes. 2. We have a lot of people that are anti-renewable, in particular solar, and have tried to legislate it off the farms. They changed the zoning and the requirements such that it's been really hard to help a farmer out and put a small array on a farm to do a community-based solar program. 3. Policy-wise, the fact that we are not developing ground mount right now is driven by the policy changes. 4. There's definitely a local regulatory process that kicks in and has led to projects not being successful.	2. I only see a very few solar developers who are going in and saying, "I'm going to do agrivoltaics, I'm going to do crops under the panels, I'm going to do grazing." It's usually they've gotten there because they've been forced to by government requirement or they've been forced to because of the preference of one of their customers. 3. A customer expressing a preference is a way to get that outcome with a carrot, a government requiring it is a way to get to that outcome with a stick. And both are really effective policy tools. 4. The bees or the sheep are examples of, "If you allow us to zone this project, we will do this mixed-use thing to benefit the community."

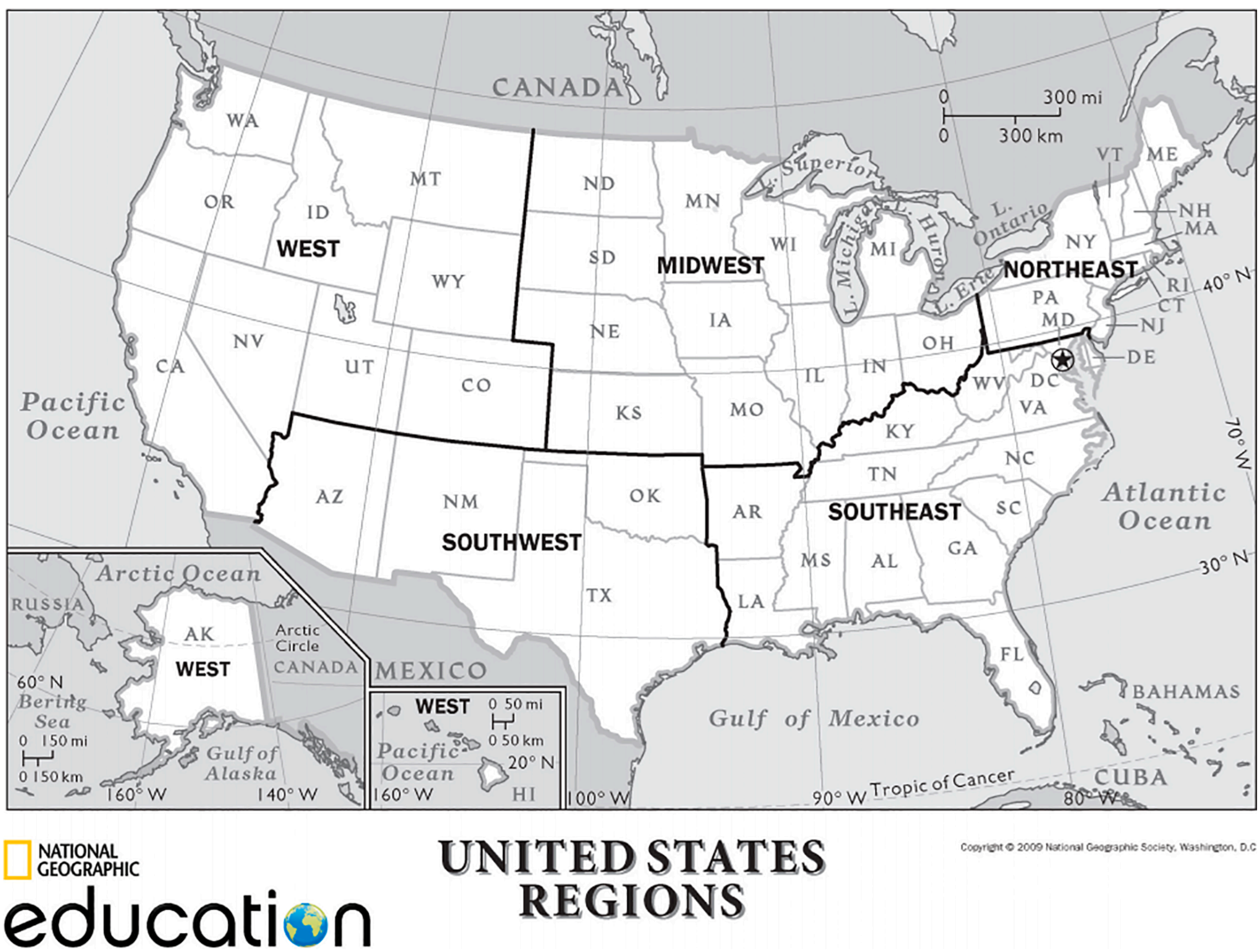

Fig. 1. United States Regions (source: National Geographic Society).

study, which includes field tests on a solar farm in Texas that is ongoing. Given that this is a novel concept, would you be willing to answer some questions about mixed use solar involving farmed meat rabbit? If yes:

a. What do you think are the biggest opportunities for this kind of mixed use solar development?
b. What do you think are the biggest barriers for this kind of mixed use solar development?
c. How much additional revenue per year would you need to see to consider allowing rabbits on your solar site?
d. To install a rabbit farm additional fencing is needed along the base of the PV arrays. What are thoughts about this additional expense and what is your minimum acceptable rate of return (MARR) for the added investment?

6. What do anticipate will be the primary siting challenges for agrivoltaic "solar farms"?
a. Would you anticipate an agrivoltaic farm helping you with zoning and permitting?
7. Would you anticipate an agrivoltaic farm reducing community pushback to solar development?
8. Is there anything else you'd like to tell me about your perspectives of mixed-use solar PV development- in general or combined with meat rabbit farming?
9. Do you have suggestions of other experienced solar professionals I should speak with?

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