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Stakeholder interactions around solar siting on agricultural lands: Toward socio-agrivoltaic interventions

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Abstract:

A record amount of large-scale solar development is proposed and under construction in the US Midwest, much of it for agricultural land. Building solar power on agricultural land entails unique challenges and stakeholder conflicts, which have been insufficiently addressed in the social science literature on renewable energy and public acceptance. Some scientists and engineers seek to manage conflicts and drawbacks of agricultural land conversion for solar use through combining farming and solar energy generation, a practice called agrivoltaics. However, this literature has not accounted for the social and stakeholder dimensions of these challenges. Who are the stakeholders involved in agricultural solar siting, and how do their epistemic paradigms about using agricultural land, especially prime farmland, differ? How are they interacting to coproduce decisions about solar siting? How is the existing context of energy and agricultural systems affecting solar siting, and who are the potential winners and losers in this process? To answer these questions, interviews were conducted across energy, agriculture, government, and expert stakeholders. The results provide a conceptual map of stakeholder interaction on solar development on agricultural lands and characterize the main epistemic paradigms shaping stakeholder conflict. Using this, we argue that agrivoltaics are currently treated as a technological fix, and we identify interdisciplinary research priorities to develop socially robust designs.

Keywords: utility-scale solar siting, solar on agricultural land, agrivoltaics, prime farmland, stakeholder engagement, food-energy nexus

Introduction

Several years ago, a fourth-generation farmer growing row crops (e.g., beans, wheat, corn) in Michigan wanted to lease land for wind power. Having coped with climate variability, he did not believe in anthropogenic climate change. Nevertheless, he saw wind power as a win-win because he could diversify his income while growing crops around turbines, and he recognized his strategic infrastructural location near a substation with available transmission capacity. Much to his chagrin, the community and zoning board stopped the project. He lamented that a handful of outspoken community members blocked it using scientifically disproven ideas about human health and avian impacts. He believes the state government should develop siting standards instead of leaving permitting to contentious and capricious local planning processes. He views solar power as less desirable than wind because it is difficult to also farm the land. (Grazing sheep under panels might alleviate concerns, but he does not currently raise livestock). He would at least want a guarantee that the land would return to farming. While he prefers solar power be developed on marginal rather than prime agricultural land, he believes landowners have the right to decide for themselves.

This interview summary encapsulates key benefits, tensions, and paradigms influencing farmers and farming communities' decisions to host utility-scale solar generation. Solar power costs have plummeted [1,2], and US utility companies are setting ambitious decarbonization goals to be achieved through solar power. As of August 2021, there are 73,000 MW of proposed solar generation in the Midcontinent Independent System Operator's transmission queue. MISO states with the most proposed solar capacity include Indiana (17,202 MW), Illinois (9,526 MW), Michigan (9,390 MW), and Wisconsin (7,961 MW) [3]. Most would be developed on agricultural land, which poses different environmental and social issues than development in desert ecosystems. A better understanding of interactions among farmers, agricultural communities, local governments, state governments, and energy companies is needed to interpret stakeholder opinions on solar siting on agricultural lands. We inquire: How do stakeholder perceptions and paradigms about using agricultural land, particularly prime farmland, differ? How does the existing context of energy and agricultural systems affect solar siting, and how are stakeholders interacting to coproduce decisions?

Our first aim is to develop a conceptual map of stakeholder interaction around utility-scale solar deployment on agricultural lands, validated using measures of stakeholder verisimilitude. To solve conflicts between land use for energy versus agriculture, scientists and engineers have recommended agrivoltaics—grazing animals or growing crops under solar panels. Our second aim is to critique agrivoltaic solutions that fail to consider stakeholder priorities as technological fixes (techno-fixes). Transdisciplinary research is needed to develop agrivoltaic interventions that improve the socioenvironmental robustness of solar siting and alleviate land-use trade-offs. The article reviews the literature on renewable energy siting, presents a stakeholder interaction model and epistemic paradigms, and discusses agrivoltaics as a potential solution. Data collection focused on Michigan, with comparison to other states to identify generalizable trends.

Literature Review

Renewable energy siting and public opposition

Despite robust social science research demonstrating multifaceted reasons for renewable energy land-use conflicts, the idea persists in public and scholarly discourses that land use challenges are minimal given the small percentage of land required to meet the world's electricity demand with utility-scale solar power [4]. In contrast, the energy and social science literature illustrates that what is often at stake is not just whether land *can* technologically support renewable energy but also whether it *ought* to be converted to energy generation [5]. Stakeholder conflict persists across diverse plots of land: places solar developers perceive to be barren desert roadside [6], land near irrigation canals with fish that provide food security to migrant laborers [7], or pristine lakeshores [8]. The surfeit of land paradigm explains public opposition as a not-in-my-backyard (NIMBY) phenomenon merely amounting to selfish desires for scenic views. While the term is pervasive in common parlance, social scientists have demonstrated that NIMBY is neither a sufficient nor analytical explanation for public opposition to renewable energy deployment.

One shortcoming of the NIMBY paradigm is that it assumes aesthetic conflicts are about physical views of renewable energy on landscapes [15]. Yet a view itself says nothing about its value to viewers [16]. Publics contest renewable energy development because it disrupts their place attachment [10]. Places are not simply groupings of physical objects. A compilation of factors—material, financial, social, and emotive—shape publics' construction of places as coherent, valuable landscapes intertwined with communities' social and individual identities. Therefore, the cost of changing a valued landscape exceeds that of losing a view [17].

For example, Moore and Hackett [6] explore how stakeholders involved in a solar siting decision engaged in a "place-making" process, through which they interwove physical and intangible place characteristics in a coherent frame substantiating the site's inappropriateness or viability for solar development. For developers, the location was appropriate because it was flat with "world-class sun," previously disturbed, near other development (e.g., golf course, highway, gaming town), and in proximity to infrastructure (e.g., transmission and natural gas lines). For opponents, the place was pristine, ecologically valuable, near conservation lands, and spiritually significant. In sum, stakeholders saw utterly different places at the same coordinates. Stakeholders and scholars have proposed GIS models to moderate such conflict [17]. However, these models have failed to integrate community perceptions, limiting their success [6,18,19].

Public opposition foments not through disembodied NIMBY opposition but via ontological interactions among publics, developers, utility companies, regulators, and experts [20]. Walker et al. [20] present a conceptual framework for understanding interactions during the siting process. However, solar siting on agricultural land has included stakeholders, interactions, and epistemological paradigms not captured in this framework. Understanding these interactions is critical for improved stakeholder engagement in renewable energy planning, which is essential for project success, procedural justice, and a desirable fit between landscapes and renewable energy [15].

Solar siting on agricultural lands

Solar siting on agricultural lands is particularly challenging because it intertwines two different and highly complex sectors—agriculture and energy—and leads to interaction among eclectic stakeholders with divergent worldviews. Next, we review relevant literature and its gaps.

Bessette and Mills [8] conducted a survey showing that opposition to wind energy in Michigan is more significant in scenic areas with natural amenities (e.g., coastal Lake Michigan) than in agricultural communities. Acceptance in agricultural communities is due to farmers' income diversification needs. However, greater comparative support in agricultural areas implies neither an absence of opposition nor an inability to block permits. For example, newcomers who migrate for the landscape's rural character resist large-scale renewables because of "aspirational ruralism," or threats to imagined pastoral ideals [12,19]. Aspirational ruralism conflicts with the paradigm that technological progress enabled by utilitarian land uses makes solar appropriate for rural landscapes [21]. This paper addresses why farmers and agricultural communities disagree on the appropriateness of solar power for agrarian landscapes.

Nicholls [22] presents a three-part typology of UK agricultural solar siting: *idealized rural land use, farming and income generation, and money making*. Stakeholders representing the first category opposed solar power for industrializing the rural landscape and consuming high-quality farmland, thereby disrupting the deep-rooted link between agriculture and rural life. They thought farmers would reap disproportionate economic benefits from solar land leases. Those representing the farming and income generation category focus on income diversification needs and portray solar power opponents as ignorant about farming's economic challenges and realities. Finally, those espousing the money-making paradigm compared privatization of solar leasing profits to profit-sharing models in community solar projects. We observe and expand on similar themes in US discourses.

To alleviate competition between agricultural and energy land uses, a growing body of scientific literature (reviewed later) proposes "agrivoltaic systems," or simultaneously using land for solar power and agricultural or biofuel crop production, or solar power and pollinator habitat [23]. This literature treats agrivoltaic solutions as techno-fixes to land use trade-offs and community opposition. A technological fix, or techno-fix, is defined as "[using] new technologies to avoid making social or political changes in societies that are in some sense under stress" [24]. The assumption is that technological substitution will preclude changes in lifestyles and social practices. For example, Späth [25] speculates that dual land uses could alleviate food-energy land use conflicts in Switzerland.

The technical literature insufficiently considers economic and social concerns, particularly given the differences between agriculture and energy systems. Dual land use does not de facto reduce opposition to solar power. For example, some stakeholders in Nicholls' study viewed dual land uses, such as grazing sheep, as disingenuous, which deepened distrust. Pascaris et al. [23] conducted 14 interviews with farmers to examine adoption of growing crops under solar panels. The authors define agrivoltaics as a "technological innovation" to be "adopted." In contrast, we view agrivoltaics as a new set of sociotechnical practices and systems requiring deep cross-sector cooperation and community engagement to succeed. Indeed, Pascaris et al.'s evidence supports this, illustrating market incongruence between energy and agriculture and financial risks to farmers from agrivoltaic participation. Solar plants generate stable revenue through power purchase agreements for 25 years, but the market for suitable livestock or crops could change dramatically over this time.

Establishing realistic stakeholder expectations is vital in agrivoltaic project design. Social scientists have found that setting expectations high and disappointing them often impedes technological deployment [26]. Further, the trade-offs of solar and agrivoltaic initiatives are site-specific. Achieving social and environmental benefits requires robust stakeholder collaboration and public engagement to tailor benefits to specific socioeconomic contexts and build trust so benefits and drawbacks are equitably distributed.

Methodology

Our study design focused on representing multiple stakeholder groups. We conducted 50 interviews with 59 people, 35 of whom were from Michigan. The sample included academic experts (n=8), utilities and solar developers (n=12 with 17 interviewees), policy practitioners including a subset focused on engineering and economic feasibility (n=16 with 17 interviewees, plus one written response), farmers and farm organizations (n=8 with 10 interviewees), and community organizations (n=5). We contacted 117 potential interviewees to request participation, sampled based on the relevant policy organizations at local and state levels, utility company type (investor-owned, municipal, rural electric cooperative), academics researching this area, and farmers affected by renewable energy siting. We conducted hour-long videoconference interviews from October 2020 to April 2021. To ensure each group received equal attention, pairs of researchers focused on each of the five stakeholder groups. The lead author attended most interviews. In this paper, we identify interviewees by stakeholder group and number.

Interviews were professionally transcribed. We coded the transcribed responses using Atlas.ti. Three team members did most of the coding, with the lead author reviewing to ensure uniformity. We used theoretical, analytical, and descriptive coding, with a total of 351 codes. The theoretical codes came from renewable energy siting literature [6,17,19,24,27,28]. We grouped codes into 10 overarching themes: agrivoltaics, pollinator habitat, wildlife and environment, agriculture, policy, land use and place, epistemology, energy, references to states outside Michigan, and cooperation and engagement. We sorted codes into groups and wrote memos on each. We supplemented interview data by attending five webinars on solar and agricultural siting. We also attended a virtual town hall for the Carroll Road Solar Farm and a Michigan Senate hearing on tax policy.

To develop the diagram, we compared the Michigan-focused interviews to 55 interviews conducted with a key regulatory or policy organization, utility company or developer, and agricultural stakeholder across 18 states to identify generalizable aspects of the interaction. We sent the draft diagram to 24 interviewees for feedback and received 17 responses, which we used to revise the diagram.

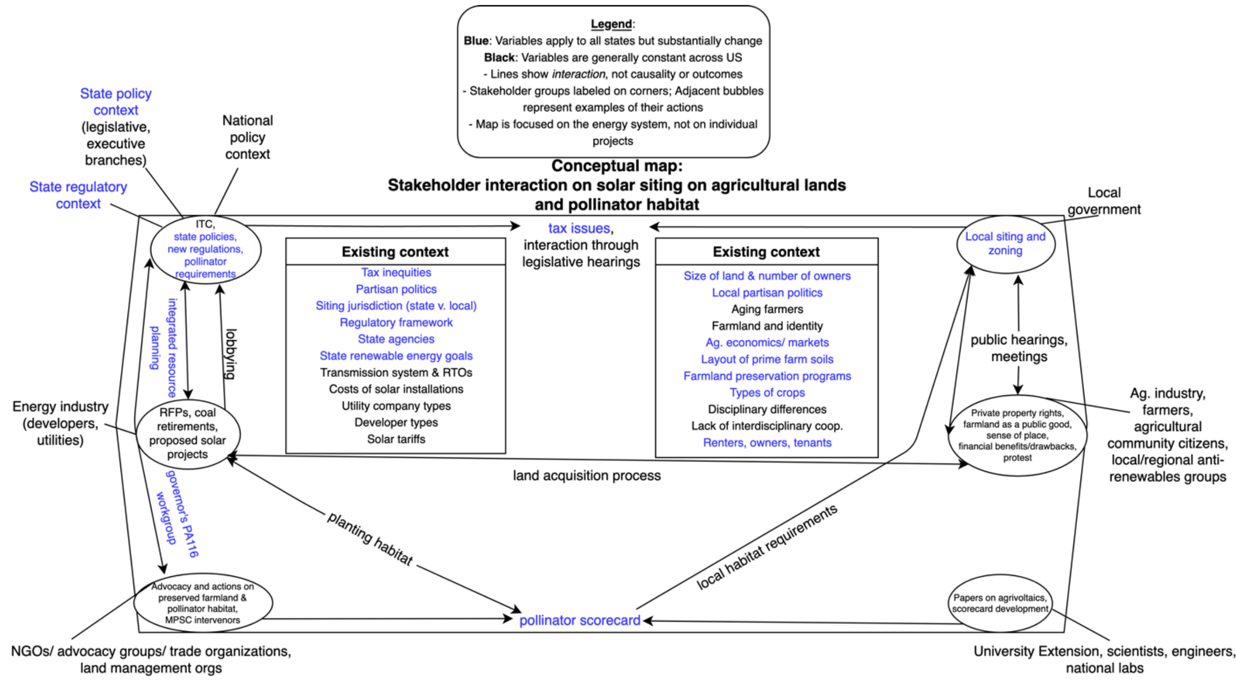

Figure 1: Stakeholder interaction around siting solar power on agricultural land

Federal and state government

The first part of the analysis addresses the left side of Figure 1, explaining interactions among national policy, energy industry, and advocacy groups.

Federal government

The federal government's central role in solar deployment has been the Investment Tax Credit (ITC): a 26% tax credit on residential and utility-scale solar installations (Fig. 1, top left) [29]. The ITC will drop to 22% for projects beginning construction in 2023 and 10% for projects starting in 2024, although Congress might extend the credits [29]. While not specific to agricultural land, the impending deadline incentivizes greenfield development because it is generally faster. Developers must adhere to federal legislation (e.g., Endangered Species Act, Migratory Bird Treaty Act, Clean Water Act) and, where applicable, the National Environmental Policy Act.

State policy and regulation

Most US renewable energy governance occurs at state and local levels (Fig. 1, top left). State legislatures play varying roles. In Michigan, a 2008 energy reform package required 10% of electricity sales from renewables by 2015, later increased to 15% by 2021 [30]. However, this is not incentivizing utility-scale solar development on agricultural lands because utilities already met the targets. Rather, multiple interviewees indicated that integrated resource plans (IRPs) required by the state legislature and led by the state regulator—Michigan Public Service Commission—led to utilities' increased solar goals. According to an interviewee (energy 6), "[for investor-owned utility companies Consumers and DTE], solar was the go-to resource for all of the needed capacity [in the IRP]." DTE aims to reach net-zero greenhouse gas emissions by 2050 and, according to interviewees, expects to increase its solar goals in the upcoming IRP. In its first IRP, Consumers Energy planned for 6,000 MW of solar power by 2030, subsequently increasing to 10,000 MW. Scholars should consider IRPs among policies driving agricultural land conversion to solar power (e.g., portfolio standards, renewable energy credits, and procurement requirements) [31].

The state government also interacted with industry to meet developers' needs for agricultural land. Michigan's previous governor forbade solar development on agricultural land preserved under the Michigan Farmland and Open Space Preservation Act, or Public Act (PA) 116. In 2018, Governor Whitmer established a workgroup to change this (Fig. 1 interactions, from bottom to top left). This decision was coproduced across sectors including policy agencies (e.g., Michigan Department of Agriculture & Rural Development), economic and business stakeholders, a clean energy industry advocacy organization, local government advocacy organizations, an environmental NGO, and agribusiness organizations. One workgroup participant said, "We didn't really have anybody that was committed to blocking it. Everybody [in the workgroup] was trying to work through it pretty collaboratively." This policy change enabled solar development on agricultural lands, allowing a 239 MW installation (Assembly Solar) to begin construction.

Developers interviewed for this study agreed on the factors that make agricultural land desirable for utility-scale solar power. Most importantly, the existing transmission grid constrains site selection. Many interviewees cited a rule of thumb that each additional mile required to reach the transmission system adds $1 million to project costs (Fig. 1, context). Agricultural land is often located near substations and transmission lines. Previously tilled agricultural land provides numerous contiguous acres of relatively flat land without rocks and trees. Contiguous land reduces operations and maintenance (O&M) costs and improves economies of scale. Agricultural land rarely provides critical wildlife habitat. These factors reduce the cost of environmental surveys and site preparation. Additionally, agricultural drainpipes can prevent flooding of solar facilities, although construction can damage them. Finally, rural agricultural land costs less than urban land and avoids the liability and geotechnical issues and small project sizes associated with brownfield development [32].

Local government

Local siting jurisdictions

Across the United States, solar siting is under state or local jurisdiction or both [31]. States with local siting jurisdiction provide more agency to local stakeholders, but this can lead to gridlock. Michigan has 1,773 local jurisdictions with zoning authority (e.g., setbacks, vegetation establishment, permits) to permit renewable energy (Fig. 1, top right) [33]. A single solar project can traverse multiple zoning authorities with conflicting regulations. Unlike Southwestern states, Michigan has limited federal land (e.g., only 610 acres of Bureau of Land Management land) [34]. Whereas Texas has large ranches with a single landowner, agricultural producers own less land in Michigan and other states east of the Mississippi River. Therefore, developers must negotiate with more landowners. In Texas, solar capacity has already reached 5,354 MW, with numerous large projects underway [35,36].

Local-state government interaction: Taxes

While not specific to agricultural land use, tax policy plays an vital role in solar development nationwide. Taxes can provide significant income to small communities. For example, the 150 MW Onion River Solar project will annually provide $250,000 to Holland, Wisconsin (population 3,756), and $350,000 to Sheboygan County (population 115,340) [37]. Since agricultural land is taxed at low rates, conversion to solar power increases tax revenue. Local governments' tax needs may outweigh community desires for land to remain in farming.

Underlying inequities in tax policy compose part of the context shaping solar deployment (Fig. 1, context box). Interviewee policy-econ 2 explained that "the State of Michigan has established a financial structure for local governments that is one of the most limited in the country." When home prices rebounded after the Great Recession, tax revenue did not because a constitutional amendment limits property tax increases to the inflation rate [38]. The state is supposed to redistribute 21.3% of sales tax to local governments but has stopped [35]. Therefore, where developable land is limited, land conversion to solar generation bears an opportunity cost compared to land uses with higher tax rates (e.g., housing) [32]. In other states, the tax context is less constrained, but tax policy still engenders conflict. An interviewee from a solar development company working in the south-central United States explained that his company faces opposition from farming communities over tax rates rather than land use trade-offs.

State and local governments interact around tax policy (Fig. 1, top corners). In 2020, the Michigan legislature considered replacing taxes on utility-scale solar facilities with a flat, per megawatt rate called a Payment in Lieu of Taxes (PILOT). Introduced by two Republican senators, these bills set the PILOT at $3,500 per MW [39,40]. The Michigan Senate Finance Committee held a hearing on these bills on September 20, 2020, facilitating interaction across state and local governments, industry, and advocacy organizations. For state governments, the tax structure for utility-scale solar power serves various purposes, including achieving environmental policy goals and promoting economic competitiveness. For Michigan Republicans, solar tax policy presents an avenue for reducing taxes and promoting small government. Politically conservative advocacy groups (e.g., Chamber of Commerce, a Republican energy organization) supported the PILOT, asserting Michigan's onerous taxes resulted in solar development going to other states. Local government representatives opposed the bills, citing a lack of evidence that $3,500/MW was fair. Governor Whitmer vetoed the bills to enable the tax commission to identify an appropriate rate for future legislation. Several other states use PILOTs or similar models, with varied reimbursement rates per year: Ohio $6,000–$9,000/MW, Virginia $1,200/MW, and Wisconsin $4,000/MW [41–43]. Several local governments in New Mexico, New York, South Carolina, and Texas have implemented their own PILOT rates [44–47].

While the Walker et al. model discussed in the literature review treats developers as monolithic, the PILOT interaction highlights inconsistencies among them (Fig. 1, middle left). Pine Gate Renewables, a medium-sized developer, is scoping projects up to 20 MW in Michigan. A company representative testified that such projects are financially infeasible without tax abatement. Large companies that chiefly develop projects larger than 50 MW did not testify (e.g., NextEra Energy, Entergy, Enel, Invenergy). In interviews, a prominent developer expressed ambivalence toward PILOTs. Another developer interviewee (energy 13) explained:

> We've got a target return [on investment] that we need to hit in order for our company to feel comfortable dedicating the resources and the capital for a particular project. So, to the extent that there is a [government] incentive, we're just socializing that incentive right back to the buyer.

In other words, the developer would reduce the wholesale electricity price in an amount commensurate to the tax reduction. Overall, state and local governments and developers are interacting around tax considerations.

Agricultural community-developer interactions

A main stakeholder interaction around solar siting on agricultural lands occurs among developers, community members, and local government (Fig. 1, middle left to right). While local government interviewees preferred the developer approach them first, developers often begin years in advance by proffering leases or sales with landowners. Standard agreements include non-disclosure agreements, creating an atmosphere of secrecy until the developer eventually approaches the relevant zoning authority. Developers and contractors then conduct environmental surveys and file public documents. Zoning authorities hold public meetings where intervenors and citizens voice opinions.

Farm landowners are a central, although eclectic, local stakeholder group in solar siting on agricultural lands (Fig. 1, middle right). Their interactions with developers and land use decisions are shaped by numerous goals, including retirement options, income diversification, pride, land stewardship, and heritage. Many farmers view farming as part of their identity rather than a job [48]. They feel an "ethical relation" to their land, evoking a "moral obligation to conserve” it (p. 1127) [49]. Energy interviewee 2, who develops projects in agricultural communities, explained:

> For people who have been farming for decades, some have owned their land for more than a century. Their land is their identity. And if their crop yields are high, they’re proud. And if their crop yields are low, they’re frustrated. It's kind of who they are.

This identity-based paradigm explains why some farmers do not perceive solar power to be farming the land. An interviewee from a community organization explained that some farmers think “if you’re not planting corn or soybeans or something on [the land], you’re not farming it” (communities 1). A solar developer from the southern United States who includes sheep grazing in projects explained that this increases support in some communities. For other communities:

> The fact that we’re shifting agricultural use by raising perennial forages harvested with livestock that go to market was just different than the corn and soy that has been grown on that land. And it felt to me, personally, that it wasn’t valued [by] that community that we were going to keep it in ag production because it wasn’t a typical corn production model. They didn’t want to see our solar panels. I don’t feel like any level of agricultural production was going to help that community accept that particular project.

Farming also relates to family lineage and retirement. Interviewee ag 2 queried, “How does [solar leasing] fit into the long-term sustainability for my children or my grandchildren: that they’re able to make a living on this farmland that’s been in our family for multiple generations?” A solar developer explained that farmers whose children are too young to inherit land are more willing to lease their land for solar power, especially if the alternative is to sell it for a permanent land use. Leasing or selling agricultural land for solar power is also a retirement option for farmers. The US farming population is aging, and many farmers are nearing retirement. In 2017, 8% of farmers were younger than 35, 58% were between 35 and 64, and 34% were 65 or older [50]. Interviewee ag 6 stated, “If you’re 65 and if you’re looking to retire, and you don’t have kids to take over the farm operation, [solar] might be the right thing for you.”

The agricultural economy is an existing context shaping and being shaped by solar leasing (Fig. 1, right context box). Smaller farm operators face difficult financial situations. Small farm revenue averaged only $93,700 in 2021, and operators are dependent on off-farm income [51,52]. Interviewee ag 1 reported that solar lease payments in Michigan average $800 per acre annually, ranging from $500 to $1,200, and interviewee from Texas reported a similar range. Solar leasing provides stable revenue exceeding crop income. In states like Michigan with limited irrigation (i.e., 670,212 irrigated acres of 9.7 million total acres), solar income can compensate for reduced yields from lack of rainfall [53,54]. It can also replace agricultural income in states like Arizona, where farmers are experiencing water cuts [55]. In sum, decisions about converting farmland to solar production are partly economic but are also rooted in identity and heritage.

Of this stakeholder group, tenant farmers—those who rent all their farmland—and renters are most likely to be harmed by solar leasing. Tenant farmers constitute a small proportion of US farmers but are vulnerable to total land displacement [56]. In Michigan, the average agricultural land rental price is $127/acre, well below the average $800/acre solar lease [57]. Of US agricultural land, 40%, or 353.8 million acres, is rented [58]. Most landlords (87%) are not agricultural operators and are on average 66.5 years old [58]. Nearly half (45%) have never farmed, and only 46% are part of the paid workforce [58]. They may not live in the same state or even country as their land. Landlords are more likely than owner/operators to lease their land for oil and gas development; the same is likely true for solar power [59]. The percentage of rented land greatly varies by state, so outcomes will be disparate nationwide [60].

Many farmers both own and rent farmland to increase their operation's profitability. They could lose access to rented land near a house and land that they own, making relocation difficult. Furthermore, farm laborers could lose their jobs. Additionally, interviewee ag 1 explained that most Michigan dairy farmers apply manure to land they lease. If they lose access to that land, they will incur additional costs of treating and disposing of the manure or transporting it elsewhere. Finally, while most interviewees think agricultural and solar leasing markets will remain separate, some worry that agricultural land lease prices will increase. These effects and inequities urgently require full social and economic assessment.

The racial distribution of the benefits and drawbacks of the changing spatial distribution of energy generation is a complicated inequity. While it is beyond this study's scope, it should be a future research priority. Graff et al. [61] find that, given Detroit's history as an export hub for fossil-fuel generation, Detroit residents fear large-scale urban land conversion for solar generation that would be exported to rural areas [61]. In reality, developers focus on the conversion of comparatively cheap agricultural land for solar generation to be exported partly to urban load centers. Most US farmland (98%) is White-owned, and 94% of farm operators are White [56]. Renewable energy development in rural communities will enable retirement of the coal-fired generation that has disproportionately affected people of color. However, this cross-scalar interaction is not always visible to rural communities, nor do they perceive the energy transition as beneficial despite the benefits of solar over coal. For example, farmers and nuclear power plant workers in rural Linn County (87.2% White), are fiercely contesting the replacement of a nuclear power plant with solar due to conversion of agricultural land, disruption to the agricultural economy, and loss of power plant jobs [62]. Overall, a thorough cross-scalar evaluation of job loss and economic equity based on race is needed.

Competing paradigms: Private property rights and public goods

A fundamental tension around solar land leasing was the rights of landowners compared to the agricultural community. As an interviewee (farmers 3) explained, "In agriculture as a whole, you have a wide variety of opinions of others on your property. And the how and the why around that is as diverse as [the number of people involved] in agriculture." Some interviewees argued that the decision to lease or sell farmland ought to be landowners' sole right. An interviewee (policy-econ 4) asserted, “If a farmer wants to [lease land] because it’s good economics for him, we should get out of his way.” Such arguments idolized farmers as good land stewards, shrewd businesspeople, and even visionaries. In a public meeting, a solar developer stated:

> Most businesses worry about next quarter. Farmers worry about the next generation, and if [farmers are] thinking that long term this is a good deal for them, who am I to argue?... These are landowners that are exhibiting their private property rights and exhibiting what they feel is the best thing to do with their land.

Similarly, an interviewee (communities 1) emphasized farmers’ business acumen, stating:

> This is agribusiness. It is usually sophisticated stuff. ... So [business people ask]: what ways can I diversify my income? What ways can I stabilize my ability to stay in agribusiness if I have a bad year?

In contrast, other constituencies view farmland as a public good. These interviewees addressed the community rather than individual farmers, emphasizing public policy and environmental considerations. One (policy 2) stated:

> Farmers’ private property and farm production really affects small communities. It’s not just a couple farmers changing their land use. It may truly not be appropriate to have ... if you wanted to maintain the character of that farmland to have that [solar] use there.

Policy-econ 7 emphasized rural aspirationalism (See Fig. 2):

> We need to be cognizant ... that farmland and agricultural land is truly a public good. It obviously has benefit for agricultural reasons, but it’s a natural amenity that people who don’t necessarily own the land drive by the land every day, or have just come to value it as open space, it factors into their sense of place.

Figure 2. Picture of solar protest signs near the Assembly Solar, Ranger Power, facility in Shiawassee County, Michigan. The signs line roads throughout the small town. (Photo by author, May 2021. Adjusted in Adobe Lightroom.)

These stakeholders emphasized trade-offs between food and energy production. US agricultural lands were converted to other uses at a rate of 2,000 acres per day between 2001 and 2016, mainly for low- and high-density housing developments (p. 30) [63]. While far less than 1% of Michigan's farmland would be used to meet solar power goals, interviewees used the moniker of prime farmland to emphasize the inappropriateness of solar power. Community member 3 explained that solar should be built on "agricultural land that's not prime, that is challenged by nutrient deficiencies or is drier than prime agricultural land would ideally be, or the soil type isn't suitable for commercial production of the crops." Community member 5 stated, "I really think that solar is the way. I think, also, that appropriating land that would otherwise be used to generate food is a kind of bargain with the devil." Farmer 2 argued that "it seems most logical that we would preserve the best quality, most productive soils for crop production." Nationally, the American Farmland Trust (AFT) opposes solar siting on prime farmland [64]. Oregon limits utility-scale solar plants to 12 acres of US Department of Agriculture (USDA) Capabilities Class 1 and 2 farmlands, and New York restricts solar installations to 50% prime farmland [65].

USDA defines "prime farmland" as land with "the best combination of physical and chemical characteristics for producing food, feed, forage, fiber, and oilseed crops." The broad definition also includes soil quality, adequate and dependable moisture supply from precipitation or irrigation, a favorable temperature, and acceptable acidity/ alkalinity and salt content [66]. A developer argued that it is impossible to completely avoid prime farmland because of its broad distribution (see Fig. 3) and the numerous factors involved in site selection. They stated that "project siting is almost like a Venn diagram of a hundred circles, and we're trying to find that perfect little spot in the middle there that represents everything." Katkar et al. [67] found that in

New York state, 80% of land of good or medium suitability for solar siting is agricultural land. If development on prime farmland is prohibited and new transmission is not sited, there is only enough land that scores well in all four suitability criteria to develop 5 MW of solar. Studies are needed on how local agricultural economies are affected by prime versus non-prime farmland conversion. However, objective measures are unlikely to assuage all stakeholders because place attachment is subjective.

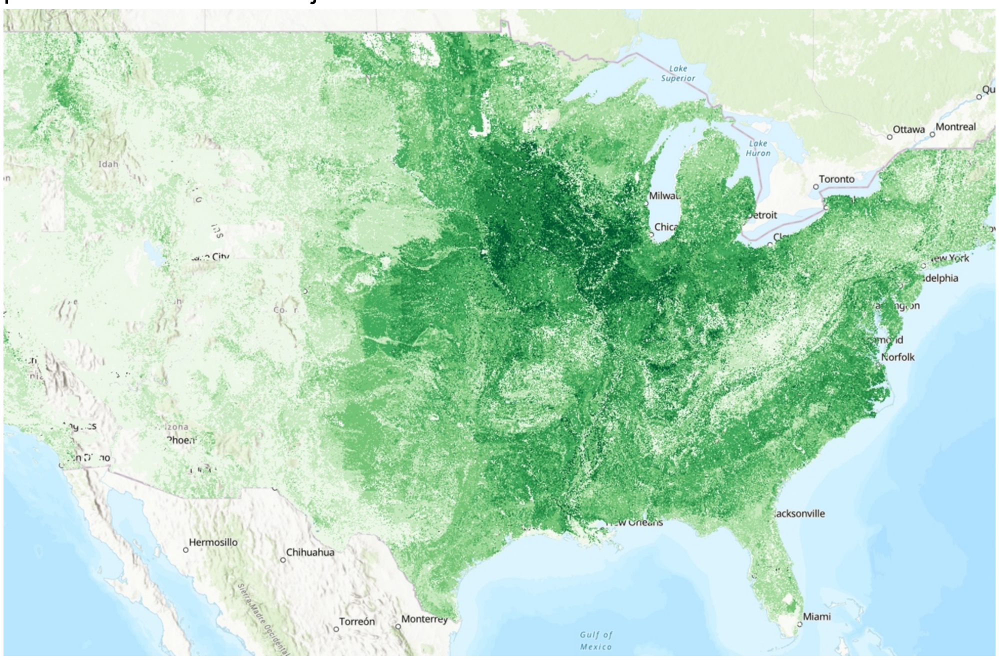

Figure 3. Crop productivity index map for the Midwest United States (Source: ESRI, ArcGIS)

Solar power as farmland preservation?

Sarah Mills (2018) has argued that wind power preserves farmland by providing additional revenue [68]. Unlike solar power, farmers can farm around the turbines. However, some stakeholders argued that the income from solar power enables farmland preservation. A written response from the Michigan Department of Agriculture & Rural Development stated, “The point of farmland preservation is to keep the land in farming. If overall farm income, including solar land rental, helps the long-term financial sustainability of the farming operation then this income option helps.” A public policy interviewee (6) explained that “for a lot of farmers and for me, farmland preservation isn’t just about preserving the physical acreage of the land. Farmland preservation at its core should be about preserving the viability of a farm long term.”

Grout, Ifft, and Malinovskaya [69] argued that energy income does not improve farms’ financial viability because it does not increase access to credit for farm reinvestment. They disregarded other spending such as retirement and children’s college tuition. Their 2014 USDA dataset showed a median farm energy lease payment of $6,000/year, far lower than the expected revenue from solar leasing at $800/acre for hundreds of acres. Data representative of average solar lease payments should be used to gauge the relationship between energy income and farms' financial viability.

In addition to revenue, stakeholders argue that solar preserves land because land leased for solar can return to farming whereas land sold for housing development is permanently converted. This is uncertain, however, because the lease could be renewed after 30 years, or the land could be sold. Land in conservation easements—agreements in which farmers sell their land's development rights—is guaranteed to return to farming. The easement manager would need to make an exception to allow for solar leasing. For time-delimited preservation programs, such as Michigan's PA 116 program, which ranges from 10- to 90-year commitments, the farmer must eventually fulfill the remaining contractual years, but it is unclear when. Stakeholders were also concerned the developer would abandon the panels. PA 116 exceptions require decommissioning costs to be placed in escrow at the project's start, negating this concern.

Scientific stakeholders: A techno-fix to a sociotechnical challenge

Scientists and engineers are also stakeholders in solar development (Fig. 1, bottom right). To address challenges of pollinator decline and reconcile conflicts between agriculture and energy, scientists and engineers are studying solar pollinator habitat and growing crops under solar panels. Researchers have modeled or experimented with several crops (i.e., chiltepin pepper, jalapeno, cherry tomato, grape, wheat, lettuce, cucumber, and corn) [70,71] [72–76]. They are evaluating crops' shade tolerance and the effects of rainwater runoff from panels and changes in soil temperature on crops [77]. The term "agrivoltaics" refers to combining solar energy and agriculture production [23]. Whereas social scientists use the term "sociotechnical" to recognize the coproduction of society and technology, agrivoltaics combines two complex technological systems without acknowledging the involved social institutions or actors.

Laird finds that, since the 1970s, advocates of utility-scale solar power presented it as a techno-fix that would avoid changes in behaviors, institutions, and grid infrastructure [24]. In reality, techno-fixes often require significant social and political changes that go unaddressed by their advocates. For example, the social science literature and this paper show how utility-scale solar power requires changes in communities, some of which are unwelcome. Similarly, agrivoltaic advocates frame agrivoltaics as a techno-fix to a straightforward trade-off between direct energy and agricultural land use. They do not address the stakeholder interactions and epistemologies or changes in the social and economic system—all of which illustrate the failure of utility-scale solar power to serve as the techno-fix promoters expected it to be.

The agrivoltaic literature also assumes positive social benefits will result from technological innovation. For example, Semeraro et al. propose building photo-ecological gardens with pollinator habitat and beekeeping, olive trees, and medicinal plants [78]. The authors excluded studying social impacts–claiming they are not measurable–yet assert that photo-ecological gardens will increase public acceptance of solar siting on agricultural land. Barron-Gafford et al. [71] are experimenting with growing crops under solar panels in arid landscapes, arguing it is a win-win because solar efficiency improvements from vegetative cooling offset crop production costs. Hassanpour et al. [79] argue that agrivoltaics are viable, using a small experimental study growing grass under panels. Ravi et al. [80] contend that shade-tolerant plants with little water needs will improve Indian farmers' cash flows, reducing poverty. Another paper claims that agave plants could be grown under solar panels to produce biofuel, combining two energy-agriculture nexus challenges without considering social, regulatory, or policy complexity [81].

The US National Renewable Energy Laboratory (NREL) and Argonne National Laboratory are studying agrivoltaics and solar pollinator habitat. The use computer modeling to argue that native grasslands developed on solar sites provide improved ecosystem services (i.e., carbon sequestration, pollinator supply, erosion control, and water retention) compared to row crops [82]. They argue that solar pollinator habitat can offset food production loss by improving agricultural pollination services [83]. NREL and Argonne are studying vegetation management at three Minnesota sites, but social science research is excluded.

Some interviewees depicted agrivoltaic initiatives as simple: merely a matter of raising panels. Interviewee ag 1 said, "They just put the solar arrays up higher so they can run farming equipment underneath it." This interviewee argued that soybeans or corn could be grown under solar panels provided there was enough space between rows for a combine. Policy-econ 3 asserted, "The cost is not that high to increase the height of the panels." The following section overviews social and market changes needed to transform agrivoltaics from a techno-fix to a sociotechnical solution.

Problematizing agrivoltaics as a techno-fix

As Pascaris et al. [23] found in their interviews, another agrivoltaic feasibility question relates to farmers' willingness to undertake agrivoltaic production. Policy-econ 9 pointed out that agrivoltaic production is complex and involves financial risks. They stated sarcastically, "Not every new and beginning young farmer, or old-timer, or somewhere in between is saying, 'You know what I really prefer to do? Stacked ag—that sounds easy.'" AFT thinks young, innovative, forward-thinking farmers could be recruited into agrivoltaics, and other farmers might become interested later. Research is needed on how to attract farmer participation and how agrivoltaics benefit and harm local agricultural economies. To ensure a just transition, decision-makers must consider effects on farmworkers, tenant farmers, farmers who both own and rent land, and landlords who are not agricultural producers. Furthermore, the benefits of solar leasing income should be weighed against the economic gains and losses of agrivoltaic production.

Comprehensive social science research is needed to gauge whether, and under what conditions, dual land uses (e.g., pollinator habitat, grazing, and crop production) will help secure community consent for solar power. At the national level, AFT (Fig. 1, bottom left) would accept some utility-scale solar power on agricultural land if it included agrivoltaics. Since place attachment differs across communities, one cannot assume dual land use will uniformly affect public acceptance. Interviewees' discussed anecdotes in which public opinion improved, worsened, and remained unaffected.

The economics of solar power must also be accounted for in agrivoltaic design. Space between panel rows is needed for agricultural machinery, increasing the land footprint per installed megawatt and therefore costs. Soybeans, for example, are low-growing but harvested using 30-ft-wide combines. High-value crops, especially those suitable for hand harvesting, might be most economically feasible (e.g., borage, calendula, oilseeds, pennycress) but vary by climate, soil type, and regional markets [84].

Additionally, raised panel height increases costs partly for additional steel and materials but primarily because of added labor and installation costs from using scissor lifts. Several interviewees indicated that a 9-foot panel clearance is needed for cattle grazing. This clearance is economically infeasible under current conditions. According to cost estimates from NREL and a prominent developer, an increase in pile height from 2-feet to 9-feet would increase pile costs by 555% and overall project costs by 12.44%. State subsidies could alleviate these costs in the upfront stages to allow for learning effects. For example, while currently only available to smaller projects, Massachusetts' Agricultural Solar Tariff Generation Unit provides $.06/kWh for solar canopies with crop production or animal grazing underneath [31].

Solar developers' business models also affect agrivoltaic feasibility. Some companies only participate in development, engineering, procurement, and construction and then sell the facility to a different company that conducts O&M. In such cases, developers have little incentive to invest in measures that reduce long-term O&M costs, such as burying cabling to allow equipment access, planting vegetation that does not require mowing, or increasing panel height to accommodate crops or native plants. Interviewees from Michigan utility companies explained that utility RFPs might include a bonus point for grazing sheep or growing crops but do not prioritize dual land uses.

While no peer-reviewed research has been published on solar sheep grazing (see Fig. 4), it is a promising agrivoltaic option. Pile height can remain the same, and sheep provide vegetation management without chewing on wires. An interviewee who develops large-scale solar projects has found that growing crops is financially infeasible but stated, "I feel strongly that managed sheep grazing is one of the few agricultural enterprises that meets our operational needs of veg[etation] management." Ideally, solar sites should be designed for grazing, including planting the vegetation palatable for sheep and providing them multiple water access points. Because sheep farming is not a major US industry, job training is needed to grow the workforce. Growth is needed in local supply chains (e.g., veterinarians, fencing, hay), mutton markets, and value-added products for wool fiber. Solar grazing interviewees explained that sheep grazing costs are equivalent to mechanical vegetation management. However, they argued grazing provides more value, such as a increased human presence on site to identify problems (e.g., erosion, broken panels), a local face to the company, good PR for keeping land in agricultural production, improved soil quality, and less damage than mechanical mowing.

Figure 4. Sheep grazing in mid-Michigan (Photo by author, September 2021. Adjusted in Adobe Lightroom)

Both solar developers and agricultural communities would prioritize research on solar power's effects on soil quality related to compaction from equipment and potential improvements in soil quality from removing it from agricultural production [8,85]. The only study on solar power and soil quality did not demonstrate improvement, but this was likely because the site's topsoil was removed [86]. Future research should measure and compare effects on soil quality at solar sites with turf grass, pollinator habitat, and grazing.

We found that agricultural and pollinator interviewees typically did not understand energy systems, and energy sector interviewees did not understand agricultural systems. To enable agrivoltaics, deep upfront collaboration would be needed among farmers, solar developers, utility companies, and researchers. Agrivoltaic innovations not tailored to farmers' needs and agricultural and energy economies and systems will fail. The critique of agrivoltaics as a techno-fix is not meant to excuse poorly planned solar development, nor is it meant to suggest that solar developers on agricultural lands ought not to do their best to avoid, improve, and ameliorate project trade-offs. Instead, we argue that carefully setting techno-realist rather than techno-utopian expectations for solar development on agricultural lands through upfront stakeholder engagement and interdisciplinary collaboration is crucial.

Conclusion

This paper overviewed the challenges and opportunities of siting solar power on agricultural land from differing stakeholder perspectives. We identified the relevant stakeholders: the federal government; state regulators and policymakers; local government; solar developers and utility companies with multiple business models; NGOs, interest groups, and industry advocacy groups; scientists and engineers; and eclectic agricultural community members. To answer our research question about how stakeholders interact to coproduce decisions, we developed a diagram illustrating their procedural and ontological interactions related to solar siting on agricultural lands. We also discussed epistemic paradigms about farmland use and changes in agricultural communities that shape this process. Two main paradigms dominate the conversation: (1) farmers' private property rights and business acumen substantiating their ability to make personal decisions with their land, and (2) farmland as a public good substantiating the perspective that solar siting decisions should be collectively governed based on community interests.

The solar siting process on agricultural land is indelibly shaped by the existing context of both the energy and agricultural systems. State and local institutions and frameworks, transmission systems, energy economies, energy legislation, partisanship, tax systems, and developer and utility business models shape the solar siting process on agricultural land. From the agricultural side, the agricultural markets, farmer demographics, land context (renters, owners, tenants, land size), and soil type are among the factors that shape solar siting. Potential winners include landowners benefitting from leasing income, beneficiaries of the added tax dollars and economic development across the supply chain, and developers and utility companies who benefit financially from successful projects. While we did not extensively address it, there are collective benefits from the low-emissions electricity and reprieve to communities where coal-fired power plants are being decommissioned. The most salient losers in the process are tenant farmers and renter-operators who lose access to their land.

We then evaluated claims that dual land uses will alleviate siting conflicts on agricultural lands. Scientists and technologists are currently treating agrivoltaic solutions as techno-fixes and ignoring energy and agricultural systems' human, social, economic, policy, and regulatory dimensions. Research needs include assessing farmers' willingness to participate in agrivoltaic initiatives, studying needs for workforce training and supply chain development for solar grazing, systematically examining how agrivoltaics affect community acceptance in different regions, and gauging whether these solutions alleviate impacts on the current losers in agricultural solar siting outcomes (e.g., tenant farmers). Agrivoltaic systems would need to become socio-agrivoltaic systems to be successful. Deep cross-sector and interdisciplinary collaboration would help enable these solutions and ensure they are improving the equity of solar siting on agricultural lands.

Bibliography

[1] M. Bazilian, I. Onyeji, M. Liebreich, I. MacGill, J. Chase, J. Shah, D. Gielen, D. Arent, D. Landfear, S. Zhengrong, Re-considering the economics of photovoltaic power, Renew Energy. 53 (2013) 329–338. https://doi.org/10.1016/j.renene.2012.11.029.

[2] R. Fu, D. Feldman, R. Margolis, US solar photovoltaic system cost benchmark: Q1 2018, National Renewable Energy Laboratory (NREL), Golden, Colorado, 2018. https://www.nrel.gov/docs/fy19osti/72399.pdf.

[3] Midcontinent Independent System Operator, GI interactive queue. https://www.misoenergy.org/planning/generator-interconnection/GI_Queue/gi-interactive-queue/, 2021 (accessed June 21, 2021).

[4] Z. Lu, Q. Zhang, P.A. Miller, Q. Zhang, E. Berntell, B. Smith, Impacts of large-scale Sahara solar farms on global climate and vegetation cover, Geophys. Res. Lett. 48 (2021) 1–10. https://doi.org/10.1029/2020GL090789.

[5] K. Gee, Offshore wind power development as affected by seascape values on the German North Sea coast, Land Use Policy. 27 (2010) 185–194. https://doi.org/10.1016/j.landusepol.2009.05.003

[6] S. Moore, E.J. Hackett, The construction of technology and place: Concentrating solar power conflicts in the United States, Energy Res. Soc. Sci. 11 (2016) 67–78. https://doi.org/10.1016/j.erss.2015.08.003.

[7] M.J. Pasqualetti, C. Schwartz, Siting solar power in Arizona: A public values failure?, in: P. Devine-Wright (Ed.), Renewable Energy and the Public: From NIMBY to Participation, 167-186 EarthScan, Oxford, 2011.

[8] D.L. Bessette, S.B. Mills, Farmers vs. lakers: Agriculture, amenity, and community in predicting opposition to United States wind energy development, Energy Res. Soc. Sci. 72 (2021) 1–11. https://doi.org/10.1016/j.erss.2020.101873.

[9] J.E. Carlisle, D. Solan, S.L. Kane, J. Joe, Utility-scale solar and public attitudes toward siting: A critical examination of proximity, Land Use Policy. 58 (2016) 491–501. https://doi.org/10.1016/j.landusepol.2016.08.006.

[10] P. Devine-Wright, Y. Howes, Disruption to place attachment and the protection of restorative environments: A wind energy case study, J. Environ. Psych. 30 (2010) 271–280. https://doi.org/10.1016/j.jenvp.2010.01.008.

[11] E.C. Larson, R.S. Krannich, “A great idea, just not near me!” Understanding public attitudes about renewable energy facilities, Soc. Nat. Res. 29 (2016) 1436–1451. https://doi.org/10.1080/08941920.2016.1150536.

[12] D. van der Horst, NIMBY or not? Exploring the relevance of location and the politics of voiced opinions in renewable energy siting controversies, Energy Policy. 35 (2007) 2705–2714. https://doi.org/10.1016/j.enpol.2006.12.012.

[13] M. Wolsink, Invalid theory impedes our understanding: A critique on the persistence of the language of NIMBY, Trans. Inst. Br. Geogr. 31 (2006) 85–91. https://doi.org/10.1111/j.1475-5661.2006.00191.x.

[14] M. Wolsink, Wind power and the NIMBY-myth: Institutional capacity and the limited significance of public support, Renew. Energy. 21 (2000) 49–64. https://doi.org/10.1016/S0960-1481(99)00130-5.

[15] M. Wolsink, Co-production in distributed generation: Renewable energy and creating space for fitting infrastructure within landscapes, Landsc. Res. 43 (2018) 542–561. https://doi.org/10.1080/01426397.2017.1358360.

[16] R. Phadke, Steel forests or smoke stacks: The politics of visualisation in the Cape Wind controversy, Env. Polit. 19 (2010) 1–20. https://doi.org/10.1080/09644010903396051.

[17] D. Apostol, J. Palmer, M. Pasqualetti, R. Smardon, R. Sullivan, eds., Conclusion: Policy recommendations for the new energy landscape, in: The Renewable Energy Landscape: Preserving Scenic Values in Our Sustainable Future, 258–270 Routledge, London, 2017.
[18] J.A. Sward, R.S. Nilson, V.V. Katkar, R.C. Stedman, D.L. Kay, J.E. Ifft, K.M. Zhang, Integrating social considerations in multicriteria decision analysis for utility-scale solar photovoltaic siting, Appl. Energy. 288 (2021) 116543. https://doi.org/10.1016/j.apenergy.2021.116543.
[19] R. Phadke, Defending place in the Google Earth age, Ethics Policy Environ. 13 (2010) 267–281. https://doi.org/10.1080/1366879X.2010.516495.
[20] G. Walker, P. Devine-Wright, J. Barnett, K. Burningham, J. Barton, B. Evans, Y. Heath, D. Infield, J. Parks, K. Theobald, Symmetries, expectations, dynamics and contexts: A framework for understanding public engagement with renewable energy projects, 1–14 in: P. Devine-Wright (Ed.), Renewable Energy and the Public, EarthScan, Oxford, 2011.
[21] R. Phadke, Resisting and reconciling big wind: Middle landscape politics in the new American West, Antipode. 43 (2011) 754–776. https://doi.org/10.1111/j.1467-8330.2011.00881.x.
[22] J. Nicholls, Technological intrusion and communicative renewal: The case of two rural solar farm developments in the UK, Energy Policy. 139 (2020) 111287. https://doi.org/10.1016/j.enpol.2020.111287.
[23] A. S. Pascaris, C. Schelly, L. Burnham, and J. M. Pearce, Integrating Solar Energy with Agriculture: Industry Perspectives on the Market, Community, and Socio-political Dimensions of Agrivoltaics, Energy Res. Soc. Sci.. 75 (2021) pp. 1–15. doi: 10.1016/j.erss.2021.102023
[24] F. Laird, Solar Energy, Technology Policy, and Institutional Values, Cambridge University Press, Cambridge, 2001.
[25] L. Späth, Large-scale photovoltaics? Yes please, but not like this! Insights on different perspectives underlying the trade-off between land use and renewable electricity development, Energy Policy. 122 (2018) 429–437. https://doi.org/10.1016/j.enpol.2018.07.029.
[26] H. Van Lente, Forceful futures: From promise to requirement, (43–64) in: N. Brown, B. Rappert, A. Webster (Eds.), Contested Futures: A Sociology of Prospective Techno-Science, Ashgate, Aldershot, England; Burlington, VT, 2000.
[27] P. Devine-Wright, Renewable Energy and the Public: From NIMBY to Participation, EarthScan, Oxford, 2011.
[28] R. Smardon, I. Bishop, R. Ribe, Chapter 3: Managing new energy landscapes in the USA, Canada, and Australia, in: D. Apostol, J. Palmer, M. Pasqualetti, R. Smardon, R. Sullivan (Eds.), The Renewable Energy Landscape: Preserving Scenic Values in Our Sustainable Future, Routledge, London, 2017.
[29] Solar Energy Industries Association, Solar investment tax credit (ITC). https://www.seia.org/initiatives/solar-investment-tax-credit-itc, n.d. (accessed May 26, 2021).
[30] M. Helms, Energy waste reduction saves Michigan customers nearly $1.2B; wind continues to dominate as renewable energy source, Michigan Public Service Commission. https://www.michigan.gov/mpsc/0,9535,7-395-93307_93313_17280-552142--,00.html, 2021 (accessed June 4, 2021).
[31] G. Byrne, Farmland solar policy design toolkit: How to craft solar regulations that work for your state and community, Farm and Energy Initiative Vermont Law School, 2020. https://farmandenergyinitiative.org/projects/farmland-solar-policy/policy-design-toolkit/.
[32] T. Spiess, C. de Sousa, Barriers to renewable energy development on brownfields, J. Environ. Policy Plan. 18 (2016) 507–534. https://doi.org/10.1080/1523908X.2016.1146986.

[33] S. Mills. Zoning datasheet, Michigan Department of Environment, Great Lakes, and Energy, 2021. https://docs.google.com/spreadsheets/d/1jsDcA_H1gjk7gHJjF6kwW2v0whUeHrIs4ZWLdFPe2WQ/edit#gid=1663952994, (accessed September 18, 2021).
[34] C.H. Vincent, L.F. Bermejo, L.A. Hanson, Federal land ownership: Overview and data, Congressional Research Service, Washington, DC, 2020. https://fas.org/sgp/crs/misc/R42346.pdf.
[35] Electric Reliability Council of Texas, Seasonal assessment of resource adequacy for the ERCOT region (SARA). http://www.ercot.com/gridinfo/resource, 2021 (accessed May 26, 2021).
[36] Samson Solar Energy Center. https://samsonsolarenergycenter.com/, n.d. (accessed September 8, 2021).
[37] Alliant Energy, Onion River Solar Project. https://www.alliantenergy.com/OurEnergyVision/AdvancingCleanEnergy/SolarGeneration/WisconsinSolar/OnionRiverSolarProject, n.d. (accessed August 22, 2021).
[38] E. Walcott, A refresher on Proposal A and local property taxes, MSU Extension. https://www.canr.msu.edu/news/a_refresher_on_proposal_a_and_local_property_taxes, 2016 (accessed June 2, 2021).
[39] C. Vanderwall, Senate Bill 1105 (2020), Michigan Legislature. http://www.legislature.mi.gov/(S(3yzcf3aittoenwrbfluhm5so))/mileg.aspx?page=BillStatus&objectname=2020-SB-1105, 2020 (accessed May 6, 2021).
[40] K. Daley, C. Vanderwall, Senate Bill 1106 (2020), Michigan Legislature. http://www.legislature.mi.gov/(S(fx5qnrtgysv135w4sjrnpcqr))/mileg.aspx?page=GetObject&objectname=2020-SB-1106, 2020 (accessed May 6, 2021).
[41] E. Schumann, R. Olin, Shared revenue program (county and municipal aid and utility aid), Wisconsin Legislative Fiscal Bureau, Madison, 2017. https://docs.legis.wisconsin.gov/misc/lfb/informational_papers/january_2017/0018_shared_revenue_program_informational_paper_18.pdf, (accessed August 22, 2021).
[42] P.K. Hall, E. Bachelor, E. Romich, Farmland owner's guide to solar leasing, Ohio State University Extension; National Agricultural Law Center; USDA National Agricultural Library, 2019. https://farmoffice.osu.edu/sites/aglaw/files/site-library/Farmland_Owner%27s_Guide_to_Solar_Leasing.pdf.
[43] E. Gilliland, A. Palmer, D. Falk, Large-scale solar development: A playbook for southwest Virginia, SolSmart, The Solar Foundation, 2020. https://swvasolar.org/swva-solar-playbook/ (accessed August 22, 2021).
[44] New York State Energy Research and Development Authority, Solar Payment-In-Lieu-Of-Taxes PILOT toolkit, n.d., https://www.nyserda.ny.gov/-/media/Files/Programs/NYSun/Solar-PILOT-Toolkit.pdf
[45] J.D. Rhodes, The Economic Impact of Renewable in Texas, IdeaSmiths LLC, Austin, 2020. https://acore.org/wp-content/uploads/2020/04/Economic-Value-Renewable-Energy-Texas.pdf.
[46] S. Riggs, J. Sedillo, Comprehensive Annual Financial Report: Year Ended June 30, 2018, Chaves County, New Mexico, 2018. https://www.chavescounty.gov/DocumentCenter/View/622/2018-Comprehensive-Annual-Financial-Report (accessed August 23, 2021).
[47] Orangeburg County Development Commission, Companies planning investments at $9.3 million. https://www.ocdc.com/news/companies-planning-investments-at-9-3m, n.d. (accessed August 23, 2021).
[48] C. Vayro, C. Brownlow, M. Ireland, S. March, "Farming is not just an occupation [but] a whole lifestyle": A qualitative examination of lifestyle and cultural factors affecting mental

health help-seeking in Australian farmers, Sociol. Rural. 60 (2020) 151–173. https://doi.org/10.1111/soru.12274.
[49] J.J. Vaske, C.A. Miller, T.P. Toombs, L.A. Schweizer, K.A. Powlen, Farmers' value orientations, property rights and responsibilities, and willingness to adopt Leopold's land ethic, Soc. Nat. Resources. 31 (2018) 1118–1131. https://doi.org/10.1080/08941920.2018.1463423.
[50] US Department of Agriculture, US Census of Agriculture: Highlights Farm Producers, National Agriculture Statistics Service, 2019. https://www.nass.usda.gov/Publications/Highlights/2019/2017Census_Farm_Producers.pdf.
[51] US Department of Agriculture, Economic Research Service, Farm sector income & finances: Farm business income. https://www.ers.usda.gov/topics/farm-economy/farm-sector-income-finances/farm-business-income/, 2021 (accessed September 7, 2021).
[52] J. Brown, J. Weber, The Off-Farm Occupations of US Farm Operators and Their Spouses, US Department of Agriculture, Economic Research Service, 2013. https://www.ers.usda.gov/webdocs/publications/43789/40009_eib-117.pdf.
[53] US Department of Agriculture, Table 1 Irrigated Farms in the Censuses of Agriculture: 2017 and Earlier Censuses, National Agricultural Statistics Service, 2018. https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Farm_and_Ranch_Irrigation_Survey/fris_1_0001_0001.pdf (accessed June 5, 2021).
[54] S. Roth, California farmers are planting solar panels as water supplies dry up, Los Angeles Times (Online), 2019. http://www.proquest.com/docview/2413340940/citation/AB555905532246D6PQ/1 (accessed June 5, 2021).
[55] B. Poole, Colorado River shortage to hit Pinal County farmers with $66M loss, Casa Grande Dispatch, 2021. https://www.pinalcentral.com/casa_grande_dispatch/area_news/colorado-river-shortage-to-hit-pinal-county-farmers-with-66m-loss/article_bf49e61f-27c1-574f-8032-c61c96fcbe78.html. (accessed September 24, 2021).
[56] M. Horst, A. Marion, Racial, ethnic and gender inequities in farmland ownership and farming in the US, Agric. Hum. Values. 36 (2019) 1–16. https://doi.org/10.1007/s10460-018-9883-3.
[57] US Department of Agriculture, 2020 State Agriculture Overview Michigan, National Agriculture Statistics Service, 2020. https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=MICHIGAN (accessed May 15, 2021).
[58] US Department of Agriculture, Farmland Ownership and Tenure: 2012 Census of Agriculture Highlights, National Agriculture Statistics Service, 2015. https://www.nass.usda.gov/Publications/Highlights/2015/TOTAL_Highlights.pdf (accessed October 21, 2021).
[59] C. Hitaj, J. Weber, K. Erickson, Ownership of Oil and Gas Rights: Implications for US Farm Income and Wealth, US Department of Agriculture, 2018. https://doi.org/10.22004/ag.econ.276228.
[60] US Department of Agriculture, Tenure, Ownership, and Transition of Agricultural Land Methodology and Quality Measures, National Agricultural Statistics Service, 2015. https://www.nass.usda.gov/Publications/AgCensus/2012/Online_Resources/TOTAL/quality_measures/ttalqm15.pdf (accessed June 8, 2021).
[61] M. Graff, S. Carley, D.M. Konisky, Stakeholder perceptions of the United States energy transition: Local-level dynamics and community responses to national politics and policy, Energy Res. Soc. Sci. 43 (2018) 144–157. https://doi.org/10.1016/j.erss.2018.05.017.

[62] NextEra offers assurances for solar farm in Palo, The Gazette, 2021. https://powerlinks.news/nextera-energy/news/nextera-offers-assurances-for-solar-farm-in-palo (accessed August 19, 2021).
[63] J. Freedgood, M. Hunter, J. Depsey, A. Sorensen, Farms under threat: The state of the states, American Farmland Trust, Washington, DC, 2020. https://s30428.pcdn.co/wp-content/uploads/sites/2/2020/09/AFT_FUT_StateoftheStates_rev.pdf (accessed February 19, 2021).
[64] American Farmland Trust, Solar Siting Guidelines for Farmland, 2020. https://s30428.pcdn.co/wp-content/uploads/2020/01/AFT-solar-siting-guidelines-Jan-2020.pdf (accessed July 20, 2021).
[65] Oregon Department of Land Conservation and Development, Natural resources and renewable energy: Renewable energy siting. https://www.oregon.gov/lcd/NRRE/Pages/Energy-Siting.aspx, n.d. (accessed June 2, 2021).
[66] US Department of Agriculture Natural Resources Conservation Service (Caribbean Area), Prime & other important farmlands definitions. https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/pr/soils/?cid=nrcs141p2_037285, n.d. (accessed May 26, 2021).
[67] V.V. Katkar, J.A. Sward, A. Worsley, K.M. Zhang, Strategic land use analysis for solar energy development in New York State, Renew Energy. 173 (2021) 861–875. https://doi.org/10.1016/j.renene.2021.03.128.
[68] S. Mills, Wind energy and rural community sustainability, in: W. Leal Filho, R.W. Marans, J. Callewaert (Eds.), Handbook of Sustainability and Social Science Research, Springer International Publishing, Switzerland, 2018, pp. 215–225. https://doi.org/10.1007/978-3-319-67122-2_12.
[69] T. Grout, J. Ifft, A. Malinovskaya, Energy income and farm viability: Evidence from USDA farm survey data, Energy Policy. 155 (2021) 112304. https://doi.org/10.1016/j.enpol.2021.112304.
[70] R. Aroca-Delgado, J. Pérez-Alonso, Á.J. Callejón-Ferre, B. Velázquez-Martí, Compatibility between crops and solar panels: An overview from shading systems, Sustainability. 10 (2018) 743. https://doi.org/10.3390/su10030743.
[71] G.A. Barron-Gafford, M.A. Pavao-Zuckerman, R.L. Minor, L.F. Sutter, I. Barnett-Moreno, D.T. Blackett, M. Thompson, K. Dimond, A.K. Gerlak, G.P. Nabhan, J.E. Macknick, Agrivoltaics provide mutual benefits across the food-energy-water nexus in drylands, Nature Sustainability. 2 (2019) 848–855. https://doi.org/10.1038/s41893-019-0364-5.
[72] P.R. Malu, U.S. Sharma, J.M. Pearce, Agrivoltaic potential on grape farms in India, Sustain Energy Technol. Assess. 23 (2017) 104–110. https://doi.org/10.1016/j.seta.2017.08.004.
[73] H. Marrou, L. Dufour, J. Wery, How does a shelter of solar panels influence water flows in a soil-crop system?, Eur. J. Agron. 50 (2013) 38–51. https://doi.org/10.1016/j.eja.2013.05.004.
[74] H. Marrou, J. Wery, L. Dufour, C. Dupraz, Productivity and radiation use efficiency of lettuces grown in the partial shade of photovoltaic panels, Eur. J. Agron. 44 (2013) 54–66. https://doi.org/10.1016/j.eja.2012.08.003.
[75] D. Majumdar, M.J. Pasqualetti, Dual use of agricultural land: Introducing “agrivoltaics” in Phoenix Metropolitan Statistical Area, USA, Landsc. and Urban Plan. 170 (2018) 150–168. https://doi.org/10.1016/j.landurbplan.2017.10.011.
[76] T. Sekiyama, A. Nagashima, Solar sharing for both food and clean energy production: Performance of agrivoltaic systems for corn, a typical shade-intolerant crop, Environments. 6 (2019) 65. https://doi.org/10.3390/environments6060065.
[77] C. Dupraz, H. Marrou, G. Talbot, L. Dufour, A. Nogier, Y. Ferard, Combining solar photovoltaic panels and food crops for optimising land use: Towards new agrivoltaic

schemes, Renew Energy. 36 (2011) 2725–2732. https://doi.org/10.1016/j.renene.2011.03.005.
[78] T. Semeraro, A. Pomes, C. Del Giudice, D. Negro, R. Aretano, Planning ground based utility scale solar energy as green infrastructure to enhance ecosystem services, Energy Policy. 117 (2018) 218–227. https://doi.org/10.1016/j.enpol.2018.01.050.
[79] E. Hassanpour Adeh, J.S. Selker, C.W. Higgins, Remarkable agrivoltaic influence on soil moisture, micrometeorology and water-use efficiency, PLoS ONE. 13 (2018) e0203256. https://doi.org/10.1371/journal.pone.0203256.
[80] S. Ravi, J. Macknick, D. Lobell, C. Field, K. Ganesan, R. Jain, M. Elchinger, B. Stoltenberg, Colocation opportunities for large solar infrastructures and agriculture in drylands, Appl. Energy. 165 (2016) 383–392. https://doi.org/10.1016/j.apenergy.2015.12.078.
[81] S. Ravi, D.B. Lobell, C.B. Field, Tradeoffs and synergies between biofuel production and large solar infrastructure in deserts, Environ. Sci. Technol. 48 (2014) 3021–3030. https://doi.org/10.1021/es404950n.
[82] L. Walston, Y. Li, H. Hartmann, J. Macknick, A. Hanson, C. Nootenboom, E. Lonsdorf, J. Hellmann, Modeling the ecosystem services of native vegetation management practices at solar energy facilities in the Midwestern United States, Ecosyst. Serv. 47 (2021) 101227. https://doi.org/10.1016/j.ecoser.2020.101227.
[83] L.J. Walston, S.K. Mishra, H.M. Hartmann, I. Hlohowskyj, J. McCall, J. Macknick, Examining the potential for agricultural benefits from pollinator habitat at solar facilities in the United States, Environ. Sci. Technol. 52 (2018) 7566–7576. https://doi.org/10.1021/acs.est.8b00020.
[84] D. Wyse, N. Jordan, Forever Green Crop Summaries, University of Minnesota, 2017. https://www.forevergreen.umn.edu/documents/2page-crop-summaries (accessed May 24, 2021).
[85] E. Uebelhor, O. Hintz, S.B. Mills, A. Randall, Utility-scale solar in the Great Lakes: Analyzing community reactions to solar developments, Sustainability. 13 (2021) 1677. https://doi.org/10.3390/su13041677.
[86] C.S. Choi, A.E. Cagle, J. Macknick, D.E. Bloom, J.S. Caplan, S. Ravi, Effects of revegetation on soil physical and chemical properties in solar photovoltaic infrastructure, Front. Environ. Sci. 8 (2020). https://doi.org/10.3389/fenvs.2020.00140.