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Good fences make good neighbors: Stakeholder perspectives on the local benefits and burdens of large-scale solar energy development in the United States

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ABSTRACT

In order to meet decarbonization goals, the number of large-scale solar (LSS) facilities in the US is expected to increase considerably. The advantages of LSS over fossil-fueled power generation are numerous and well documented. However, residents living nearby proposed and existing LSS sites have voiced a number of concerns about LSS, including its possible impacts to farmland and agricultural production, biodiversity, stormwater runoff, home and property values, as well as concerns about solar panels' toxicity and safety. While rapid expansion of LSS currently relies on officials permitting and residents being willing to host these systems, the appetite for LSS in some communities may be waning. Here we examine the perceived benefits and burdens of recent LSS developments, conducting 54 interviews with a broad set of stakeholders including residents, officials and developers at seven LSS sites across the US. We focus on identifying residents' most common concerns regarding LSS systems across states, site types, landscapes and ownership structures. We find concerns are associated with either LSS development processes or impacts, and center on the type and amount of information provided, the community's influence over project design, the efficacy of community subscription efforts, as well as projects' economic, environmental, and visual and landscape impacts. Importantly, we also investigate strategies that have been employed to improve perceptions and project outcomes, which include increasing in-person engagement, more explicit discussion of project tradeoffs, third-party intermediaries acting as community champions, and explicit requirements for meaningful local economic benefits.

1. Introduction

Recently the Biden Administration set an aggressive goal of decarbonizing the United States (US) power sector by 2035 and achieving a net zero-emission economy by 2050 [1]. In order to meet that goal, large-scale solar (LSS) (defined as ground-mounted systems with at least 1 MW_{ac} in capacity) and wind energy systems have been projected to increase 5 to 10 times their current installed capacities of 74 gigawatts (GW) and 143 GW, respectively [2]. The advantages of LSS and wind energy over fossil fueled power generation are significant, and include avoided climate damages, improved air quality and public health, reduced water withdrawals, and drought-proof revenue for landowners, specifically farmers leasing land to host turbines or solar arrays [3–7]. Perhaps as a result, the popularity of both technologies in national surveys remains high with approximately two-thirds of US adults favoring both prioritizing their development and the US taking steps to become carbon neutral by 2050 [8].[1]

Driven by rising electricity prices and demand, along with increased local opposition to wind energy projects, developers, utilities and policymakers have switched their focus to expanding LSS in rural communities, where a dramatic increase in deployment has been evidenced [13]. By the end of 2024, the EIA [2] predicts an additional 63 GW of

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[1] Other national surveys and polls show majority US support for renewable technologies and decarbonization [9–12]

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solar to be installed in the US compared to only 12 GW of wind. Rapid expansion of LSS in the US currently relies on officials either at the local, state or (rarely) federal level providing appropriate land use permits, and, often, residents being willing to host these systems. Yet residents and officials' support for local LSS projects and proposals is and has been far lower than national surveys would suggest [14–19]. Here we examine the perceived benefits and burdens of recent LSS development across the US, conducting interviews with a broad set of stakeholders including residents, officials and developers at seven different LSS sites. We also work to identify barriers to and opportunities for centering community values and objectives in LSS development. Ultimately, these interviews are intended to answer two research questions (RQs): (RQ1) what are residents' most common concerns regarding LSS systems across states, site types, landscapes and ownership structures? And, (RQ 2) what strategies have developers and officials employed, or could employ, to improve perceptions and project outcomes and better align LSS development with local land-use plans, community needs and values?

The remainder of this paper is structured as follows. In the next section we review the existing literature examining the commonly perceived benefits and burdens of LSS, often referred to as the social or community acceptance of solar [20–22] to identify research gaps. In the section following, we describe the methods we use to attempt to close those gaps and answer our research questions. In Section 3 we present our interview results, addressing our two research questions with illustrative quotations where appropriate. In the final section, we discuss the broader implications of this work for community-centered solar development (CCSD) more generally.

1.1. Perceived benefits and burdens of LSS

This study focuses on the siting and planning of LSS; however, the perceptions, responses, and concerns of local host community members are reminiscent of those pertaining to the planning and siting of other large-scale energy infrastructure. A vast and rapidly expanding body of research exists around community responses to energy infrastructure siting, such as wind (e.g., [23–30]), electricity transmission (e.g., [31,32]) natural gas infrastructure (e.g., [33–36]), nuclear power and waste (e.g., [37–39]), hydrogen (e.g., [40]), carbon capture and storage (e.g., [41]), and, increasingly, solar (e.g., [15–17,42–45]). LSS tends to be thought of as less visible, more environmentally benign, and requiring fewer hosting landowners (parcels) compared to other energy infrastructures like wind plants, transmission lines, or nuclear plants. But the growing literature on LSS community-response coincides with the rapid and widespread deployment of LSS globally (with solar now representing the largest source of new electric generating capacity additions annually in many countries [46]), as well as the rise in host community concerns, opposition, and conflict over siting as LSS penetration increases. As described in the section below, much of the emerging literature around LSS siting and community response aligns with and reinforces findings from research focused on other energy infrastructure, but there are also important distinctions, research gaps, and key insights specific to LSS.

Previous work demonstrates that community members perceive local economic benefits of LSS in the form of both direct payments to leaseholding landowners, which can facilitate farmer succession plans, and increased tax revenues to the community at-large [15,47]. However, the perceived burdens of LSS are far more prevalent in the scientific literature, popular press, and at local meetings, often stemming from concerns about LSS removing land from agricultural production (e.g., "food vs fuel") and LSS negatively impacting wildlife (e.g., birds, bats and terrestrial fauna), ecosystems, biodiversity, stormwater runoff, and home and property values [19,21,44,48–51]. Community members also raise concerns about the noise of LSS, the toxicity of panels, their safety and cost, the materials and mining required for construction, decommissioning, and LSS arrays' end of life (EOL) and the efficacy of photovoltaic (PV) recycling. Often such concerns may or may not be supported by or even directly contradict scientific reports, such as regards the economic competitiveness of solar with natural gas generation [52] and the lack of toxicity associated with both the breakage and disposal of PV modules [53,54]—significant growth in solar PV recycling is expected, but often as a necessary response to widespread PV EOL and waste by 2050 [55,56].

Perhaps the most frequently referenced impact of LSS, both at meetings and in the literature, is its impact to the viewshed and surrounding landscape [15,17,47,57,58]. LSS is most commonly constructed on large flat open landscapes, such as farmland or deserts, that have previously been free from structures. Thus the installation of LSS often represents a development, industrialization, or in the least a "disturbance" of areas that were previously open and scenic [59]. Concern is greatest when LSS development is perceived as a threat to meaningful place characteristics to which residents are particularly attached (e.g., rural, bucolic countryside) [16,17]. As the size of individual LSS projects continue to increase, their landscape impacts also increase, perhaps leading to the positive relationship detected between LSS size and opposition [16,60].

Beyond the perceived impacts of LSS, concerns stem from siting and permitting processes that are perceived to be unfair, exclusionary, performative, or result in unjust distributions of both the costs and benefits of development [17]—though Enserink et al. [47] identify that scholars may focus more on process than do laypeople who instead focus on impacts due to their inability to affect process. Certainly some concerns are amplified by the increased politicization of renewable energy [61], vocal minorities of residents that are more invested in stopping or delaying projects than majorities of residents that are quietly supportive [15,62], and well-funded organized (often) ex-local opposition groups that use efficient communication networks (e.g., Facebook) and misinformation to stoke fear and distrust of local officials, subject-matter experts, developers and the technologies themselves [15,63].

How then to increase both the real and perceived benefits of LSS and reduce its burden on communities? Attempts to mitigate community members' concerns about LSS vary, but common forms include increased (or improved processes of) stakeholder engagement by developers, local officials or third-parties, either within or outside of standard public consultation processes. Whether or not these processes reduce actual impacts or merely alter how those impacts are perceived remains an important question [64]. Another attempt involves the use of unique ownership structures that increase the economic benefit and local control of or influence over LSS, i.e., community ownership or community subscription. But do such structures also reduce negative impacts? Perhaps the most common attempt includes physical alterations to LSS systems intended to improve landscape fit, such as adopting different setback distances, buffers, fences and screening, and even the adoption of agrivoltaic systems, or dual land use models that accommodate, synergize or simply compromise agricultural and power production [49,65,66].

Another attempt at reducing the perceived burden of LSS includes siting systems not on farmland or "greenfields," but instead on disturbed or degraded land such as capped landfills, closed power plants, or previously contaminated sites, i.e., "brownfields" [67]. Industry experts perceive less public opposition to redeveloping brownfields with solar compared to conventional renewable energy projects [68], and the amount of LSS on these disturbed lands has risen significantly in the last few years [69]. However, the extent to which state and federal decarbonization goals can be met using this land is unknown. Additionally, the constraints of "brownfield solar" vary, and may include technical and environmental barriers such as clean-up of previous site contamination and disturbance of prior remediation work, financial and regulatory challenges such as securing capital investments and reducing liability and risk, and social challenges such as local opposition [68].

A final complication involves how research into the benefits and burdens of LSS has proceeded. Much of the social science research on

LSS relies either on national surveys targeting individuals' general attitudes or support for hypothetical projects, e.g., [12,42] or targeted cases studies that focus on only one or a small number of LSS projects in a particular state or region e.g., [15,17]. However projects differ considerably and necessarily across the US. States have different renewable portfolio standards, utility regulatory environments and siting authority levels for LSS, and policies that often determine the size of projects developers are willing to pursue so as to avoid either local or state-level approval processes. Both natural and political environments also vary across states and communities, leading to different land and project types, along with unique permitting processes. Thus, exploring the most common burdens and benefits of LSS requires both a broad and deep approach: broad enough to capture a diversity of projects and stakeholder experiences, but also deep enough to distinguish meaningfully between them. Some scholars have adopted this approach, most notably Susskind et al. [51] and O'Shaughnessy et al. [70]. Here we engage in a similar process, examining a diverse set of stakeholders' attitudes, support, concerns and preferences for LSS at recently completed projects in different regions across the US, and across different site types, project designs, ownership structures, and development processes.

2. Methods

2.1. Rationale of design

To answer our RQs we used a qualitative comparative case-study design, which relies on comprehensive descriptions of particular cases, and their complexity and uniqueness [71,72]. This research design is uniquely adept at capturing the *subjective* experience of individuals, as well as identifying variables, structures, and types of interaction between participants. Importantly, case studies also generate "context-dependent knowledge," which aids in developing a "nuanced view of reality" [73], work that is difficult to accomplish via quantitative research methods.

2.2. LSS site selection

To capture the most common perceptions of LSS, we used a diverse case approach to capture a wide range of LSS sites and experiences [74]. We identified seven projects that differed across key factors including location (e.g., urban, rural, state and region), project type (i.e., greenfield, agrivoltaic, and brownfield), ownership structure (e.g., utility-owned, independent power-producer (IPP), community owned or subscribed), state and municipal laws in effect (e.g., zoning authority, renewable portfolio standards, property or excise tax structures in effect, zoning ordinances, land-use codes), size, topography, local ecosystem (e.g., flora, fauna, biodiversity), and year of completion (2018 to present). Across these key selection factors, we also sought sites with varied setback distances, vegetative buffers and screening, solar panel array heights and tracking axes, and fence types and heights. It is important to note that our initial goal was to learn from what were considered "successful LSS projects," or projects that were built and operational, with a focus on determining not only why those projects were built, but also the most common ways in which they were perceived positively by residents, officials and developers. These results, while not intended to be representative, would inform a representative national survey of LSS neighbors that would be conducted at this project's conclusion. We recognize that this focus limits the external validity of our findings to some extent, ignores the important lessons and experiences that can be learned from examining "unsuccessful projects," and has been criticized previously [75]. At the same time, one result of this study is that "success" is in the eye of the beholder: despite 6 of the 7 sites being constructed, residents often perceived project completion as the result of a failed rather than successful process.

To ensure sufficient variety, we initially constructed a sample of potential LSS sites using i) conversations with and suggestions from practitioners and subject-matter experts, ii) national and regional media accounts referencing successful LSS projects, iii) keyword searches using the site-selection criteria mentioned above, and iv) a review of existing datasets and relevant geographic-information system (GIS) mapping tools, including inSPIRE Agrivoltaics Map, CEQ Climate and Economic Justice Screening Tool (CEJST), RePowering Mapper 2.0 (now 3.0), ArcGIS EIA Large-scale PV Solar Sites, and EIA-860 data. These strategies resulted in an initial sample of over 125 LSS sites. We reduced this number via iterative discussion amongst the project team and our Technical Advisory Council (TAC) made up of officials, developers, scholars, and energy justice and community organizations, and more in-depth analysis of the key factors described above. Specifically, we categorized the initial sample of sites by project type, then categorized sites by region, permitting authority, size, whether they were within or close to an environmental justice community, and finally whether they were sufficiently close to a reasonable number of neighboring homes (to enable a large interview pool). This process ultimately led to a sample of 14 prospective sites that maximized the diversity of the key factors discussed above. We then presented and discussed the merits of each site with our TAC, ultimately selecting 7 final sites, and using the other 7 sites as backups.

Table 1 presents descriptors of the 3 greenfield, 2 brownfield, 1 formerly contaminated site, and 1 agrivoltaic project included in our final sample. These projects were located in Arizona, Colorado, Florida, Iowa, Michigan, Rhode Island and Texas. Four of the 7 sites were located within a census tract designated as environmental justice (EJ) communities (i.e., "disadvantaged") by the Climate and Economic Justice Screening Tool (CEJST) developed by the US White House's Council of Environmental Quality. Identifying information about each site has been withheld to protect interview participants' identity and confidentiality.

2.3. Interview protocol development

To answer our research questions, we developed an interview protocol by reviewing and expanding on previous case study work examining perceptions, attitudes, and opposition to LSS development qualitatively [15,16,21,45,76–78]. We developed three linked interview protocols for use with i) neighboring residents, ii) developers, and iii) local officials including township and county board members, supervisors, and planning commissioners, ultimately adding a fourth protocol that focused on iv) public works and municipal utility personnel. All interview protocols were reviewed by our TAC.

These interview protocols (available in the Supplemental Materials) included questions regarding: i) individuals' initial attitudes and preferences regarding solar and changes in each across the project timeline; ii) the type, timing and effectiveness of different communication channels and participation methods; iii) levels of trust between residents, officials and developers; iv) LSS site design elements, zoning and permitting processes; and v) community values and previous experience with development. Additionally, all interviewers focused on identifying developers and officials' best practices of, lessons learned from, and key challenges of developing LSS, advice for future communities undergoing LSS development, and recommended research for improving LSS design and development processes.

2.4. Interview sample

We identified study participants at each of the 7 sites via Internet searches of developer, municipal, county, local media and utility websites and used site maps and special use permits when provided by developers or officials, or Google Earth searches, to identify neighboring residents. Those individuals for which we could attain email addresses or telephone numbers we contacted before visiting the site to either schedule an in-person interview or conduct the interview over the phone or via Zoom or Teams. For those individuals who did not initially

Table 1
LSS case-study site descriptors.

Site no.	Project type	Year	Region	Rural /urban	Project size (MWac)	Ownership structure	State zoning	State RPS	EJ community
1	Agrivoltaic	2020	West	Rural	1	Community (Subscribed)	Dual (Local & State)	YES	NO
2	Greenfield	2021	Southwest	Rural	137.5	IPP	Hybrid (Local <25 MW)	EXPIRED	NO
3	Greenfield	2020	Southeast	Rural	74.5	Municipal	Hybrid (Local <75 MW)	NO	YES
4	Greenfield	2020	Midwest	Rural	100	IPP	Hybrid (Local <100 MW)	YES	YES
5	Brownfield	2018	Midwest	Urban	1.3	IPP	Local	YES	YES
6	Brownfield	(est.) 2023	Southwest	Urban	50 + 2	IPP[a]	Local	YES	YES
7	Superfund	2020	Northeast	Urban	3.5	IPP + Community (Subscribed)	Hybrid (Local <40 MW)	YES	NO

[a] : Project initially contained a community subscription element, but was retracted before construction began.

respond, email reminders and follow-up calls were conducted after one week. In-person interviews were conducted over the course of seven 2–3 day visits at each site, between June and November 2022. During each visit, we knocked on doors of neighboring residents both in homes and apartments. We also relied on snowball sampling when necessary.

Table 2 shows the number and type of individuals interviewed across the 7 sites. 104 individuals were emailed, called or agreed to participate upon our meeting in-person—this number does not include residents that answered their door, but preferred not to participate, nor residents who did not answer their door. Fifty-four individuals were interviewed in total, 38 in-person, 13 via Zoom or Teams, and 3 over the phone. We purposely did not ask interviewees demographic questions; however, we identify 38 participants as male, 16 as female; 4 interviewees were Hispanic/Latino/a; the rest were white. Our sample skews older; nearly all of our interviewees appeared to be over thirty years old. Phone and zoom interviews tended to be longer (between 30 and 75 min) than in-person interviews (between 5 and 45 min). All but 2 of the phone and zoom interviews were with professionals (i.e., developers, officials or utility personnel) rather than residents. We did not note any differences in interview quality or responses between modalities such as "choppy purviews" [79], likely due to most of our virtual participants being professionals with high-speed internet; however, we did note that, as has been proposed previously [80], nearly all of the residents interviewed in-person, regardless of their position on LSS, expressed appreciation for the opportunity to speak about the project. One couple in Arizona even identified their interview experience as equivalent to therapy.

2.5. Data analysis

Audio-recorded interviews were transcribed and detailed notes describing interviews, both those audio-recorded and not recorded, were prepared immediately following the interview by the interviewer in either MS Word or Excel. Numerous residents were uncomfortable about or declined to be recorded. While this may be a limitation with respect to capturing all of these interviewees' exact words, interviewers took written notes during every interview conducted, and always expanded on these notes immediately following the interview—at only one study site did two interviewers work together. These interview notes and transcriptions were analyzed thematically both immediately following the interview and throughout the data collection period [81].

Table 2
Interviewee counts. LSS Case-Study Site numbers are being withheld to protect participants' confidentiality.

Site no.	Developer[1]	Neighboring residents	Govt[2]	Utility	*Subtotal*
Withheld to protect		8	1		*9*
participant	2	8	1		*11*
confidentiality	3	3	2		*8*
	2	3	3		*8*
	2	1		2	*5*
		9		1	*10*
				3	*3*
Subtotal	**9**	**32**	**7**	**6**	**54**

[1] : One interview with a solar lease-holder was conducted using the developer protocol.
[2] : One representative of a community-benefit organization focusing on agrivoltaics was interviewed using the local-official protocol.

Specifically, immediately following each interview, interviewers engaged in an inductive process of analysis bolding key phrases, terms or concerns that were either common to other interviews, were novel understandings, perceptions, or strategies regarding LSS, or provoked investigation in subsequent interviews. After all in-person visits to each study site were complete, the interviewer compiled a list of themes from the notes or transcripts and presented them to the full study team for consideration. Ultimately a list of 16 themes or categories of themes, e.g., "residents' concerns over project design", was generated and each was described in a shared document with relevant quotes or points of discussion from the 7 sites listed below each theme. After each in-person visit was complete, the interviewer would check themes against the existing list and either incorporate them or create a new theme and discuss it at a subsequent full-team discussion. This deductive process led to the reclassification and regrouping of some themes, and ultimately reduced the list of 16 themes, or categories of themes, to the 11 subheadings identified in Section 3. This type of analytic deliberation allowed us to summarize data, highlight key features and generate insights intended to answer our two research questions. For instance, when multiple residents at different sites noted they had not been approached to participate in their project's community subscription, the interviewer presented this information to the full study team, and it was decided to specifically ask developers and local officials about their subscription efforts in subsequent interviews.

Four co-authors conducted interviews, with the lead author conducting interviews at 5 of the 7 sites. Intercoder reliability was not calculated due to many of the interviews not being recorded. To improve reliability, the lead author led the thematic analysis across all sites in coordination with other interviewers. This study was reviewed and determined to be exempt by Michigan State University's Institutional Review Board (IRB), Study ID No. STUDY00007162, the University of Michigan's IRB, Study ID No. HUM00217618, and Lawrence Berkeley National Laboratory's Human & Animal Regulatory Committees Protocol No. Pro00023268.

3. Results

3.1. RQ1: residents' most common concerns regarding LSS development

Across all 7 sites, residents' most common concerns regarding their local project centered around perceptions of the *process* of LSS development or the development's *impacts*. These concerns are described in the sections below, with our key findings described in Table 3 alongside recommendations for improving the development process or the impacts of LSS.

3.2. Process concerns

Process concerns centered on the i) amount and adequacy of information dissemination, ii) community members' influence and understanding of project attributes, and iii) the efficacy of community subscription efforts. Each is discussed below.

Table 3
Key findings. Concerns of LSS development and recommendations for developers and officials. Sections in which the concerns and recommendations are discussed are in parentheses.

	Concern	Recommendation
1	Notices, public meetings and town halls have little to no (and sometimes a negative) effect on residents' perceptions of LSS. Many residents are unaware of these processes, resulting in their feeling 'left out,' despite developers meeting statutory obligations. (3.2.1)	Policies should be considered that require developers to engage in-person, e.g., via door-knocking and one-on-one conversations, to identify and address concerns. (3.4.1)
2	Residents often use the term "developers" to refer to project builders, owners and operators, leading to confusion and increasing distrust throughout the project lifecycle. Residents also have no opportunity to provide feedback during operational phase. (3.2.2)	Officials should delineate and communicate organizational responsibility over the full course of the project life cycle, providing contact information of operators and updates to the community when possible. (3.4.1)
3	Rural communities may become overwhelmed by the sudden influx and needs of ex-local workers engaged in LSS construction. (3.3.4)	Developers should contract with local businesses to ensure that supplies and consumables (e.g., food, building materials) are sufficient to meet community and project needs prior to construction. (3.4.4)
4	Residents living within sight of or within the municipal boundaries of LSS projects are often ignored in subscription efforts. (3.2.3)	Developers should increase their effort to subscribe local residents, at a minimum advertising opportunities via direct mail and at public meetings. (3.4.4)
5	Residents are often unaware of or struggle to describe LSS's impact on tax revenues, sometimes perceiving its generation and use by local and state government negatively. (3.3.1)	Officials should work to tie specific services to tax benefits, and state policies that exempt and replace property taxes with more regular and predictable payments, such as "payments in lieu of taxes" (PILT), can reduce confusion both for residents and officials. (3.4.1)
6	The viewshed impact of interconnection infrastructure including tie-in lines and substations are significant and ignored during planning and community engagement processes (3.3.2)	Developers should provide detailed renderings of interconnection infrastructure (in addition to the solar arrays themselves) and improve planning for tie-ins. Developers or officials should provide residents and planners tours of infrastructure at neighboring LSS sites. (3.2.1; 3.4.1; 3.4.3)
7	Previously disturbed or developed land in rural areas may not be perceived as more suitable than greenfields for LSS development. (3.3.2)	Developers and officials should not assume LSS will be perceived as a 'beneficial use' of disturbed land, and should approach the development of these sites as carefully as they do greenfield development and expect similar concerns. (3.4.3)
8	The opportunity costs associated with not developing solar are rarely a focus of conversations. (3.3.4)	Developers and officials should discuss the type of (more) permanent infrastructure that could take the place of LSS, such as subdivisions and trailer parks (3.4.1; 3.4.3)

3.2.1. Information dissemination

Providing community members access to high-quality information and meaningful opportunities to participate are key elements of a just decision-making process [82], and have been shown to drive wind project support [24,27,83,84]. Both solar developers and local officials identified that disseminating information to residents living near proposed LSS projects was challenging. Low population density, the distance between homes, a reticence by developers and officials to use the Internet to communicate information, and a lack of time, energy and other resources by residents all constrained the provision of information. Notably, and in line with findings from Jacquet [85], those neighbors who did not receive compensation from a project consistently reported feeling uninformed, upset and ignored by developers and officials, while individuals who received compensation or had been provided an opportunity to participate described a fairer and more transparent development process. A couple from Iowa who had sold a parcel of land to the developer to build a substation described the process as fair, arguing "people had a say," while another resident who lived next to the same project said, "we aren't leasing anything to them, so they didn't talk to us."

Officials and developers at every project site identified public notices (as required), town halls, briefings at township board and planning commission meetings, and signage as the principal means of disseminating information to community members. These methods may be inadequate however as thirteen residents, all of whom lived within sight of an eventual project, said they had not been aware of their local project until construction began, with one resident in Arizona saying, "All they have to do is put an alert in the newspaper, who reads the newspaper?"

Residents not only preferred direct engagement with developers, door-knocking in particular, but those who had spoken with a developer previously and in-person perceived projects more favorably. At one site, the landowner and owner of a LSS project had displayed both technical designs and artistic renditions (i.e., sketches, drawings and watercolor paintings) of the project, held informational meetings, personally communicated with and surveyed all immediate neighbors, and provided tours of their property. Neighbors (at this site and others), developers, and officials all identified that this type of visual information and grass-roots community engagement, particularly when they come early in the proposal timeline, are crucial to alleviating concerns about the project's visual impact and generating local support for LSS.

This parallels work done in wind communities showing that process and outcomes are linked, i.e., perceptions of fairness are positively correlated with positive attitudes about completed projects (though the direction of causation is difficult to discern) [84]. Conversely, two residents who were upset about the project constructed at the site in Arizona identified that early engagement would have allowed them more time to organize opposition: "Had we known it was going in, I would have gone to the neighbors and got signatures, started to protest." Indeed, organized opposition groups communicating more effectively via social media and packing local meetings with vocal opponents have both proven effective means of stalling LSS development, encouraging moratoriums and ultimately the adoption of more restrictive zoning ordinances that make projects financially infeasible [15,63]. This tension regarding the timing of engagement, i.e., that earlier engagement may lead to greater time for opponents to organize, may betray what Ryder et al. [64] call a reliance on instrumentally-driven engagement processes. These processes focus primarily on developer's instrumental needs, are oriented toward procedural compliance, and act as a procedural precursor to eventual development. More care-oriented, community-centered engagement processes on the other hand focus on shifting power imbalances, expanding the number and type of stakeholders included, and building trust [86].

3.2.2. Community influence and understanding of project attributes

Interviewees repeatedly urged the importance of officials and developers drawing on residents' first-hand, situated knowledge with regard to highly visible, physical aspects of projects [87]. The types and placement of fencing, vegetative screening and buffers, mowing and landscaping schedules and contractors, and setback distances were all identified as avenues requiring consultation of nearby residents. One example in which a resident whose recommendations were ignored stood out in Arizona. The interviewee, who was a landowner and cattle rancher, recounted urging the developer and planning commissioners to not plant oleander as a vegetative screen because the shrub can be toxic to livestock. Nevertheless, oleander was planted in the immediate vicinity of their property (see Photo 1).

At each project, residents, developers and officials agreed that the revolving door of local and ex-local actors interacting with and responsible for different elements across the project lifecycle confused and upset residents (and officials), reduced transparency, and ultimately eroded trust. This included questions regarding who was responsible for leasing, permitting, construction, operation, landscaping, maintenance, complaint resolution, and eventually decommissioning or repowering. The actor most commonly identified as being wholly responsible for the success or failure of LSS—and the term nearly always used to identify them in communities—was the "developer." Yet as one developer pointed out, their time in the community was limited. "As soon as the shovel hits the ground, we're gone". Residents desired one-on-one engagement with developers, and the advantage of developers building strong, positive local partnerships, even though such partnerships require greater time, money and resources, is clear [15,45,64]. That trust and partnership may not carry through when the project is transferred to the construction team or sold to the ultimate owner-operator has been less documented.

It was perhaps this lack of consistency and transparency that led to the number of misconceptions shared by residents. These included misidentifying the purchaser of the electricity (often argued to be an out-of-state or a politically liberal entity) and the amount of the lease payments provided. For instance, a woman living next to a site in Iowa said, "I don't understand why the power is being delivered to Illinois," yet the power generated was being purchased by the Central Iowa Power Cooperative to meet in-state electricity demand.

3.2.3. Community subscription

Research and practice suggest that community solar, identified here as LSS projects that provide opportunities for residents to subscribe, lease or purchase panels, are more positively viewed than projects that lack such opportunities [16,88]. Reasons for this include expanding access to clean energy to households lacking the resources to install rooftop solar, ensuring project benefits are localized, and promoting a more inclusive planning process [89,90]. Yet the extent to which community subscription is taken up by residents living within sight of or even within the municipal boundaries of the LSS project is unclear. Interviews with residents, developers, local officials and third-party subscription companies showed little to no recruitment or participation of individuals living near projects. Developers may promote the service to gain support, but owner-operators who are ultimately responsible for subscribing customers may then lack either the incentive or ability to do so following construction. Developers and utilities cited low population density and the distance between homes, at least in rural areas, as reasons that subscription based on geographic proximity was difficult and necessitated relying on a third-party online subscription company. One of these company representatives agreed, "it's a lot cheaper to have a software company doing the acquisition and customer management than [developers] kind of doing it." These companies use Internet advertising and easy-to-use online interfaces to sign up (often) low- to middle-income (LMI) residents in environmental justice communities throughout the utility's service area, though not necessarily near the project. When asked why community subscription did not more readily rely on geographic proximity to the project, that same representative said that doing so can lead to project benefits being captured by more wealthy residents:

> "The reality is there's a lot of discriminatory things in that. When you think about Newark and how many municipalities actually touch Newark, it's not many. Those are key people we want to support, the huge environmental justice community there. Then you have lower income communities on the coast, and they obviously don't have neighbors to the east, and so there are fewer municipalities they could possibly have a project sited in, so geographic proximity requirements we see as slowing development and reducing our ability to reach those communities."

Indeed, state lawmakers in Minnesota recognized this geographic challenge when they updated the state's community solar legislation to allow projects to be sited further from the communities they would serve in an effort to provide more access to LMI subscribers [91]. While the US Department of Energy's "Justice 40" initiative has identified that a portion of the benefits of the clean energy transition must be distributed to environmental justice communities, the extent to which community subscription actually empowers neighbors of projects (i.e., reduces utility bills or infers ownership of projects) or increases project support is unclear [92,93]. Conversely, LMI residents may also live near projects, particularly in urban areas, and could benefit from targeted subscription marketing and services, as one official in Texas noted:

> "A lot of residents suffer from high electricity bills because their homes are not weatherized, and, you know, they don't have very many options, and their incomes are fixed, or are very much below the [adjusted minimum income], so offering them an opportunity to just be able to buy into, from, or even partially own a [solar] system that would result in lower cost for them, I think, [would be] a little positive in the community."

3.3. Impact concerns

Residents' impact concerns focused on i) projects' direct and indirect economic impacts, ii) visual and landscape impacts, iii) environmental impacts, and iv) impacts at or to the rural-urban divide. Each of these concerns is discussed below.

3.3.1. Direct and indirect economic impacts

The potential economic benefits of a LSS project to a community in

Photo 1. Oleander planted as vegetative screen.

the US might include increased property tax revenue, landowner payments, and increased employment [94–96], though few peer-reviewed studies examine local or sub-state data. Of these impacts, we found those most often mentioned and salient to community members and officials were the local electrician and landscaping contracts generated by LSS development and increased business at local stores, especially during construction, which indicates that some of the economic activity is noticed by the local community. At one site, however an official in Iowa noted that this local economic boom was apparent but not without a drawback: the increased business activity had overwhelmed local stores and aggravated residents.

While the most significant of these impacts to a community may be tax revenue, few residents we spoke with were aware of local tax revenues increasing as result of the solar project, could accurately describe their amount or impact, or perceived its generation and/or use by local and state governments positively. This might be especially true for very large projects. Wind projects have been shown to contribute significantly to county and school revenue and expenditures [97,98]. One developer identified why, though, tax revenue from a single relatively small LSS project may be difficult to notice for many local residents:

> "There just isn't the money in the project to build a new school or something, you know. It's not like the way an old coal power plant was, where it would come in and there would be 500 permanent jobs…super boost the tax revenue…solar just doesn't do that…".

More commonly when solar taxes were discussed, rather than noting new state or local tax revenues, people pointed to federal income tax credits and their suspicion of them. Residents in Iowa and Colorado suggested—incorrectly [99,100]—that, "unlike coal, solar required federal tax subsidies to be economically viable." Another resident argued that developers were simply in business to secure tax subsidies: once they'd "gotten [their] government money," they "could just pack up [their] s**t and leave." Obviously, this perspective belies the considerable risk involved in LSS development.

3.3.2. Visual and landscape impacts

Landscape fit is key to minimizing the visual impact of LSS. Here design elements like the type and height of fencing and vegetative screening, the use of pollinator habitats and animal guard, and landscaping choices (e.g., groundcover, mowing schedules and weed control) all influenced support. Notable examples of improved landscape fit included a project in Colorado, which drew praise for being constructed on the east side of the main road, avoiding disturbing the mountain views that existed to the west. One local official in Michigan drew praise from residents for pressing the developer to use crushed rock to cover a brownfield LSS site, which increased the cost of the project, but improved the aesthetics of the site, which was previously marred with concrete slabs and weeds. When the local official was asked why they insisted on using the crushed rock, they said they were a resident of the neighborhood and they "didn't want to have to dodge people at the store."

One aspect of the projectscape that has so far seemingly been ignored by the literature, yet has a significant visual impact, is the project tie line, substation, pylons, utility poles, and other interconnection infrastructure. At all of the completed projects, we found the substations and tie lines to be far more visible than the solar arrays. At one site in Florida, solar arrays were barely visible from the adjacent road, while the substation and tie line rose above the treeline. At another site in Rhode Island, a planner identified that despite considerable effort to make the project visually appealing, the developer was not forthcoming about interconnection details or else lacked understanding of the utility's needs, leading to "an aesthetic problem," adding "it's really tough to cover up big poles" (see Photo 2).

Consistent preferences regarding fencing and screening were difficult to discern. Some preferred higher-cost privacy fencing and bushes

Photo 2. Visual impact of interconnection infrastructure.

that would block the project from view, others preferred farm fencing, pollinator habitat or even animal guard that would be less visible and blend more readily into the landscape.

Of course LSS is a new use for land, and a number of residents and officials identified serious concerns about LSS removing agricultural land from production. These concerns have been readily noted [15,16] and may increase as one developer noted that "95 percent of our projects are in agricultural use areas." While agrivoltaic designs have increased in number and performance [66,101], few of our interviewees were aware of them or could speak to how they might have been used to augment local projects. Instead, most residents, developers and local officials preferred development of LSS on previously disturbed or contaminated land, or brownfields, with one describing that type of development as "transformative." "Every city has a landfill," another said, "most communities are very pleased to have someone come do something with [brownfield land]." Another agreed, "community members supported [our project because of] the blight that it was before, you know, a torn-up ground, with graffiti on the fencing, the fencing torn down in areas." At the same time, developers and officials noted that development of brownfield projects is more complex, expensive and requires more involvement and collaboration between state and local officials, and utilities. A planner in Rhode Island doubted the extent to which decarbonization goals could be met using only previously disturbed land, and one developer identified that the preference for "brownfield solar" may attenuate in rural areas:

> "Generally, neighbors like living in a rural location, you go out to a rural landfill in upstate New York, and if it's not fenced and gated, people use that as their ATV park and people [are] running all over with their dirt bikes…they're out there hunting, and so sometimes, yeah, you do get some community opposition."

3.3.3. Environmental impacts

With such a significant change in land use it not surprising that residents, officials and developers noted concerns about projects' impact to local flora and fauna, stormwater runoff, water withdrawals, and even the creation of heat islands. Residents in Arizona voiced frustration about the loss of Mesquite trees and desert badgers; officials in Florida noted concern about projects' impact to gopher tortoises, caracaras (both protected species) alligators, and nearby swamps. A Texas developer identified that residents, particularly those out West, often worried about the amount of water that may be required for cleaning panels or used in concrete. Residents also voiced concern that local temperatures had increased after project construction, one in Arizona noting "the temperature has gone up so much that the trees do not get a frost now over there, and they've died." While that claim (or its attribution to the LSS project) may not be factual, the extent to which LSS may impact local temperatures remains an important question with contrasting findings in scientific studies [102,103].

Climate change concerns, which might otherwise motivate support for LSS projects, were less common amongst residents neighboring these sites. One official in Colorado lamented, "Climate change? Not many people care about that unfortunately." Alternatively, a farmer in Iowa emphasized the importance of communicating the potential impacts of climate change to both farmers and LSS project neighbors: "my piece of this is telling the story of the American farmer, it's not looking so good, and it's continuing to get harder with the context of climate change."

3.3.4. Impacts at the rural-urban divide

As has been noted in the literature [17], residents are often confused about and concerned for "where their power goes," frequently framing electricity as a natural resource being taken from them and unduly meted out to residents in more urban, progressive communities. Although this is not unlike other exports produced in rural communities (e.g., food), the electricity export was often mentioned in a negative way. At the same time, some mentioned that LSS provides opportunities to preserve the rural character of their community by slowing suburbanization and maintaining low population density. An official in Rhode Island identified LSS as a passive temporary land use that "prevents what will ultimately become of all these lands, i.e., subdivisions." When providing information, supporters urged officials, developers and advocates to delineate the opportunity costs associated with not developing solar, in particular the relatively more permanent infrastructure that could take its place, like subdivisions and trailer parks. Even a resident in Arizona who formerly farmed the land under the panels that abutted his property on two of three sides spoke positively of the solar project, saying "it's quiet, nobody else is gonna move in, no partying!"

One temporary impact may be the sudden increase in extra-local workers required to construct LSS. Around one urban brownfield project, residents barely noticed the contractors parking nearby and walking to the project site, while a local official in a rural community identified the challenge of rapidly increasing local employment and diversity in rural areas:

> "When you bring in 200-300 workers…I think it's just the not knowing, when you're such a small tight knit community, when you bring other people in, it's like a neighborhood watch alarm, what are they doing here?"
>
> They also added the local stores were not prepared for the influx:
>
> "I think this is where we needed to do a little better here, when they got up at the end of the day, it was 300 people leaving [work] into a community that was already busy enough, we couldn't keep up with milk and we didn't keep up with the beverages and snacks and gas, so it made the stores busier and it made some local people upset because they couldn't buy bread, what the heck, we can't keep bread anymore, I can't keep milk in here!"

3.4. Strategies to improve project perceptions and better align LSS development with local community needs and values

The previous section noted many of the most common perceived concerns associated with the process and impact of LSS development. In this section, we discuss the strategies discussed by developers and officials, as well as residents, that had, or would have, improved both how their LSS projects were perceived and their ultimate impacts. Their comments fell into four areas, the need to: i) increase engagement, ii) use third-party intermediaries as liaisons, iii) communicate tradeoffs of LSS explicitly and effectively, and iv) require local economic and employment benefits in LSS development. Each is discussed below using both participants' statements and evidence from the academic literature.

3.4.1. Increase engagement

A host of scholars and practitioners have identified the importance of increasing and improving direct engagement between community members, neighbors of projects, local officials and developers and operators, suggesting engagement must occur earlier, more frequently and in-person throughout not only the development process, but also during operation and the facility's decommissioning [20,24,32,64,104,105]. This study demonstrates that the required processes for informing and engaging residents are insufficient, suggesting policy changes that increase notice and engagement requirements are necessary. Here, all agreed with the sentiment of one official in Texas who stated, "the most important thing in the process is making sure the community is brought in," identifying the value in scheduling bus tours, providing classes with residents focused on job training, having coffee with neighbors, establishing and meeting regularly with community advisory groups, and providing visuals and narratives explaining and seeking feedback regarding the process, design elements, and potential outcomes of development. These methods go well beyond the required public meetings and town halls, stress in-person contact and communication, and presume residents have a meaningful role in influencing project design. One official in Iowa also identified the importance of communicating the pros and cons more readily to the broader community, noting:

> "A couple decided not to be in the program, which is fine, but I think they just didn't understand it. That's what we have to do better, communicate the pros and cons…[the developer] should have gone bigger. They only invited the people that would be looking at the panels. That started the rumor mill. You got several thousands of people not knowing anything about it."

Tax benefits of renewable projects have proven difficult for residents to appreciate [106], perhaps because officials struggle to communicate how they impact services and project owners have sometimes worked to reduce their tax liability following the completion of the project [107]. State policies that exempt and replace property taxes with more regular and predictable payments, such as "payments in lieu of taxes" (PILT), may be able to reduce confusion both for residents and officials, as well as better enable services that are a direct result of LSS and thus more salient for community-members [108].

3.4.2. Use local third-party intermediaries as liaisons

Using a third-party local intermediary to serve as a liaison between developers, officials and community members was recommended at numerous sites. Officials identified the importance of an intermediary that could "speak the local dialect, know the people, and understand the community." Even developers urged that these partners should be local "community champions," i.e., "grass-roots leaders that can get the word out about the project." Developers argued that such a liaison would allow them "to do what we're good at which is developing solar and… letting our local development partner do what she's good at which is… [working] with the local community to address their concerns from the developer side, while the government is doing it from the city's side."

Conversely, residents and officials identified the importance of these liaisons working on behalf of the community to advocate, lead collaboration efforts, and hold developers and owner-operators' "feet to the fire." Previous work demonstrates the importance of these processes being initiated by community members, in order to focus the process on expanding community-members' voice and enhancing equity in decision-making, rather than top-down instrumental government and developer-led initiatives that often focus on maintaining control or influence over the process, which often leads to frustration and greater opposition [64,109]. Another interviewee noted that local officials and law firms may be able to recommend local partners, such as researchers, students or interns from local universities, local agricultural groups, planning, economic development (e.g. chambers of commerce) and other community based organizations, as well as local community champions (e.g. [110]) that have experience leading such processes.

3.4.3. *Communicate tradeoffs of LSS explicitly and effectively*

In addition to relying on a third-party liaison, officials and developers consistently identified the importance of sharing with residents both the benefits and burdens of facilitating and restricting development. This included inviting individuals in from neighboring communities that had undergone solar development to share about their experiences, both good and bad, with a focus on the opportunity costs of decisions that in the short-term may be seen as victories for residents, but later may generate regret. For instance, increasing setback distances may be perceived by project opponents as a win, but ultimately result in land that goes unutilized, neither being farmed nor generating electricity after the project is completed. This increases the overall amount of land required to generate the same amount of electricity. Residents may also prefer types of pollinator habitats or vegetative screening that are aesthetically pleasing, but require increased water use, with one developer urging, “people who know what they're talking about on pollinators know that they don't have to be the pretty flowers…those bright flowers are frankly very hard to keep alive depending on the soil you have [and] how much water they get.”

As one official in Colorado noted, unduly restricting development may leave a subset of farmers to “struggle and challenge to continue to make a profit on their traditional farms with degraded farmland.” And urging development on previously developed or disturbed land in rural areas may not always be the preferred alternative, as residents noted these areas were valued open space, often used for recreation. Finally, officials and residents should inquire about and developers must be more explicit about the design and resulting viewshed impacts of oft-ignored and less salient ancillary design elements including interconnections, substations, tie-ins and utility poles These elements may ultimately have a greater impact on the viewshed than the panels themselves.

3.4.4. *Require local economic and employment benefits including subscription carve-outs*

Across our case study sites, there were numerous examples of local parts suppliers, electrical contractors, food service providers, and what one official identified as “pseudo-skilled laborers” engaged in or seeking greater inclusion in LSS development. Though such commitments are more often “encouraged” rather than “required” by permitting agencies in our case studies, it may be desirable for “community engaged design” along with community engagement or benefits plans to be explicitly required of future LSS projects. At the same time, despite developers lauding community subscription efforts, their programs frequently ignored project neighbors and nearby community members. Online subscriber recruitment may result in greater diversity, equity and inclusion of regional subscribers, and restricting subscription to project neighbors may discriminate against LMI households outside the community. However, failing to advertise to or include LSS project neighbors may also be discriminatory, particularly when community subscription offers are used to generate support for a proposed LSS project. Additionally the extent to which landowner payments actually go to permanent residents of the community is increasingly in doubt as much of the land underlying projects in these case studies was owned either by ex-local corporations or the developers themselves. To remedy this, one local official in Texas argued that community benefits agreements should be designed to match (at least) the market rate of that land per year. They argued those benefits should amount not “to trash pickup, but significant benefits, true benefits with perpetuity, for example employment opportunities and [reduced] energy costs.”

4. Conclusion

This study engaged a diverse group of stakeholders at 7 LSS sites across the US. The sites selected purposely varied across regions, ownership structures, project types, ecosystems, and local communities. Yet stakeholders at each site consistently identified aspects of the LSS development process, particularly how and how much information was provided, the community's influence over project design—or lack of, and whether or how community subscription efforts proceeded, that meaningfully influenced how they perceived the success of each project. Stakeholders also consistently identified the importance of meaningfully considering specific project impacts including their economic, environmental, and visual and landscape impacts, and impacts to the rural-urban divide.

While all 7 projects were completed (with the exception of 1 being constructed currently) and thus could be—and were—deemed “successful” by developers and local officials, the continued rapid deployment of LSS to meet decarbonization goals relies on the continued support and willingness of residents to host ever larger and more numerous LSS projects. We argue, therefore, that the definition of “successful” LSS development must broaden to encompass aligning with local values of, ensuring beneficial outcomes for, and earning support from local host communities not just in the short-run to obtain construction permits, but throughout operation of the project to maintain what some refer to as a "social license” to operate [111–113], but what we call “community-centered solar development”. Such support requires not only attention to process and impact, but would also benefit from the strategies identified here that work to improve alignment of development with local land-use plans and community values and objectives. These include increasing in-person engagement, more transparent and explicit discussion of project tradeoffs (both positive and negative), third-party intermediaries acting as community champions, liaisons, and even negotiators, and explicit requirements in either permits or zoning ordinances for local economic benefits.

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CRediT authorship contribution statement

Douglas L. Bessette: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing, Funding acquisition. **Ben Hoen:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Writing – review & editing. **Joseph Rand:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Writing – review & editing. **Karl Hoesch:** Conceptualization, Investigation, Methodology, Writing – review & editing. **Jacob White:** Conceptualization, Formal analysis, Investigation, Methodology, Writing – review & editing. **Sarah B. Mills:** Conceptualization, Funding acquisition, Investigation, Methodology, Writing – review & editing. **Robi Nilson:** Conceptualization, Investigation, Methodology, Writing – review & editing.

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Data availability

The data that has been used is confidential.

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