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Equity and Justice Implications for the Development and Deployment of Agrivoltaics Systems

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Abstract. This paper addresses the equity and justice issues that are directly related to agrivoltaics, largely through the lens of farmers and other rural stakeholders, but also to some extent through the eyes of commercial developers. Though clearly different in nature, both small-scale and utility-scale projects must address the equity and justice concerns of stakeholder communities in order to be successful. Further, while the ideas and principles discussed here are mostly U.S.-centric, they still apply to similar settings around the globe. The paper first reviews the concept of energy justice, drawing a distinction between justice and equity. It then moves on to the ways in which equity and justice are more specifically realized in agrivoltaics applications. Some of the main equity and justice issues are identified, particularly as they constitute barriers (real or perceived) that detract from more rapid adoption and deployment of agrivoltaics technology. In addition, the paper considers the differences in equity and justice associated with non-rural agrivoltaics applications; and it concludes with some general principles that should be followed to ensure the development and deployment of this emerging technology achieves overall success.

Keywords: Agrivoltaics, Energy Equity and Justice, Stakeholders, Community Engagement, Dual Land Use, Frontline Communities

1. Introduction

Agrophotovoltaics, or agrivoltaics, as it has come to be known, is the dual use of land for both solar energy and agricultural production. While the prospective benefits of agrivoltaics have been well-documented [1], very little research has been devoted to the concepts of equity and justice as they directly apply to the development and deployment of agrivoltaics projects. Several authors have tangentially approached the notions of equity and justice in the context of integrating solar energy production and agriculture [2,3], but today there is only one peer-reviewed paper that is wholly devoted to this idea [4]. On the other hand, energy justice is a key pillar of the Biden Administration's Justice40 initiative, and it permeates much of the U.S. Department of Energy's (DOE) investment strategy to move the country away from dependence on fossil fuels. In 2022 DOE announced an $8 million investment in projects to integrate solar energy production with farming, and additional funding is under consideration. In 2023 the U.S. Department of Agriculture (USDA) expanded funding under the Rural Energy for America Program (REAP) [5], and more support for agrivoltaics beyond what USDA has already expended may also be included within the "farm bill" currently being considered by the U.S. Congress [6]. States such as Colorado have also provided funding and other incentives to expand the deployment of agrivoltaics [7]. Nonetheless, unlike other energy technologies, the equity and justice implications of agrivoltaics remain somewhat nebulous and difficult to pinpoint. The reasons are varied, but at least partly due to the immaturity of this evolving industry.

2. Energy justice and equity

Drawing upon earlier work in environmental justice, energy justice has three main pillars: distributive, recognition, and procedural [8]. Distributive justice relates to fairness in the distribution of resources. Recognition justice is associated with the degree of respect given to different socio-cultural identities. Procedural justice concerns fairness in the decision-making process. Together, these comprise a framework for a just and equitable implementation of the energy transition. This framework is detailed in [9], which also discusses how it can be expanded to encompass other aspects, including restorative justice [10,11] (see Figure 1). The eight principles described in [12] constitute an alternative framework with which to conceptualize energy justice.

An important consideration centers on the needs of frontline or disadvantaged communities (DACs). These are groups of people who may regularly experience uncertainty at the food-water-energy nexus. They tend to have fewer advantages and access to resources, or less resources, capacity, safety nets, or political power to adapt to various risks. DACs are often at risk because of the places they live (such as in rural settings, on tribal lands, or in flood-prone areas), which may not possess the basic infrastructure to support an effective response to critical events. Hence, energy justice can perhaps be more simply defined as affordable, reliable, representative, and accessible energy for all users, regardless of socioeconomic status.

It must be noted, however, that equity and justice are not the same. Equity is process oriented, whereas justice is outcomes oriented. So, while energy equity is closely related to energy justice, they are really two different concepts, a difference that Figure 1 does not fully reflect. Achieving energy equity requires intentionally designing systems, technology, procedures, and policies *a priori* that lead to the fair and just distribution of benefits within the energy system [13], which is a more prospective, forward-looking approach. Energy justice, on the other hand, can be thought of as being more retrospective, or backward looking in an attempt to correct offenses that have been promulgated by expansion of the energy system and its technologies.

3. Justice and equity in the context of agrivoltaics

In [4], the main pillars of energy justice are operationalized in the context of agrivoltaics. Distributive justice addresses the question of who benefits from agrivoltaics; procedural justice has to do with the legal and regulatory processes and mechanisms that can be used to incentivize deployment of agrivoltaics projects; and recognition justice addresses the ways in which existing and future agricultural activities should proceed.

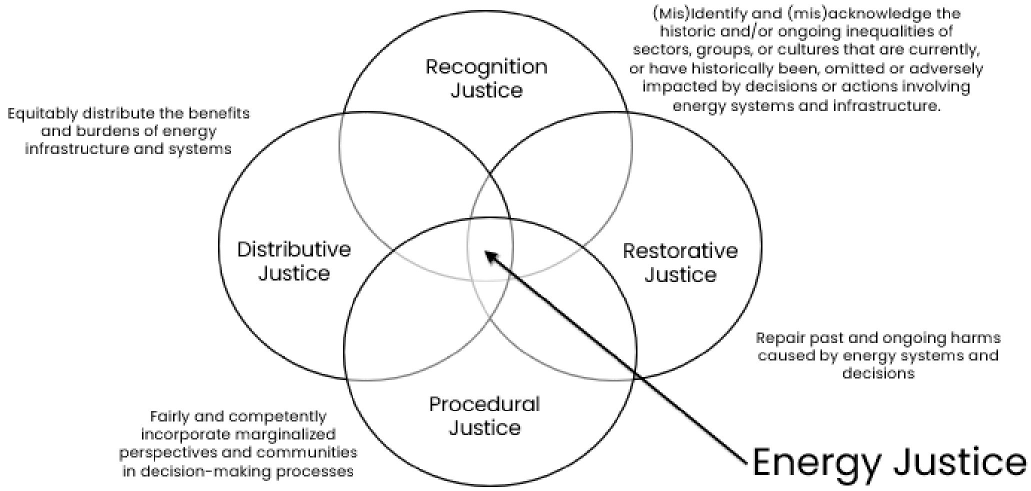

Figure 1. *A four-tenet framework of energy justice (expanded from [10] and [11]).*

While land use considerations and solar siting questions have recently been at the forefront of agrivoltaics equity, the framework proposed in [4] suggests that other important questions must be addressed. Some of these are directly tied to the size and extent of farming operations. Larger operators likely have the financial resources to cover the upfront and lifecycle costs of agrivoltaics, attract better financing and insurance terms, and still turn a profit, whereas smaller operators may not. Larger agrivoltaics installations may also be able to attract more favorable power sales arrangements than smaller ones, as well as greater access to food retailers who can purchase their locally sourced products. In addition, farmers with all sizes of operations are typically unfamiliar with the technical and ongoing maintenance issues of agrivoltaics, situations that will likely require external support and services that carry a financial burden.

Each of these issues has to do with economic fairness and equity among farmers; but there are other equity concerns as well, some of which center on the relationship between farmers, developers, and the communities in which they operate. DACs in the surrounding areas desire access to food, energy, jobs, and lower emissions which agrivoltaics deployments can supply, addressing a different level of equity and justice. Further, in the context of ever-present urban sprawl, agrivoltaics has the potential to keep farmers on their land, promoting diversification of operations and protecting it from industrial, commercial, or even residential development.

All these considerations notwithstanding, it is still somewhat difficult to ascertain how DACs or frontline communities fit into the agrivoltaics equity and justice conversation. An argument could be made that frontline communities, as typically conceived today, are not commonly associated with the agrivoltaics movement. In the energy infrastructure context, frontline communities are often thought of in terms of disadvantaged groups living close to physical structures or facilities that have historically been viewed as heavy polluters (refineries, petrochemical plants, high-traffic roadways, etc.). Although it may be possible to site an agrivoltaics project in, or close to, a frontline community, this is not typically the case, since (1) agrivoltaics equipment and infrastructure are usually deployed on agricultural lands away from the towns and communities where people live, and (2) the solar panels associated with agrivoltaics projects are not typically considered to be heavy polluters in the sense of environmental quality. Perhaps, then, it is the definition of a frontline community that needs to be expanded in the agrivoltaics conversation; or maybe frontline communities should not really be the main focus anyway. More likely what is needed is a different way of thinking about equity and justice in the agrivoltaics context; and because the technology and industry are relatively young, perhaps the greater focus should be more on equity (i.e., front-end, prospective, and process driven) to prevent the need for justice (or, coming to terms with injustices, after the fact, that may have been promulgated as the result of agrivoltaics development or deployment).

It is also important to note that energy and justice in agrivoltaics are both project- and geography-specific. Developers and private parties approach the decision to initiate an agrivoltaics project from different perspectives, and various jurisdictions (e.g., cities, counties, reservations) have different regulatory structures and cultures. The type of product to be produced (i.e., plants or animals) drives the project's thinking, as do the land characteristics. Figure 2 broadly portrays four different types of agrivoltaics projects. The equity and justice implications are different for each type.

A Type 1 project is one in which a farmer, on his or her own initiative, decides to invest in, and deploy, agrivoltaics on land s/he owns, purely for the private benefit of the farm and/or the farm family. The project generates electricity to be wholly used in farm/household operations, but most of the resulting crops are sold into the marketplace in the usual way. In this scenario, the equity and justice implications are somewhat minimized since the agrivoltaics operations are wholly or mostly contained within, and for the benefit, of the individual farm. A Type 2 project is similar to a Type 1 project, but in this case the farmer sells at least a portion of the generated electricity to the local community or grid (e.g., a community microgrid or some kind of locally distributed generation), while also selling the resulting agricultural production into the marketplace. This is essentially a private operation undertaken mostly for public or community benefit; and its public focus can engender questions that are equity- and justice-related (e.g., does the local community get access to the renewable electricity, or does the operation supply the larger utility grid that may serve cities and towns far away?). Both Type 1 and Type 2 projects may have workforce implications if employees are displaced in some way because of a change in operations or land use. A Type 4 project is one that is commercial- or utility-scale and initiated solely for the public good (although local farms and communities can be part of the public that is served). In this scenario a developer or electric utility acquires land from owners for the purpose of generating large amounts of renewable electricity with which to supply communities far and near, as well as to produce a significant volume of agricultural products for the broader marketplace. There are more equity and justice implications for this type of project because questions are immediately raised about where to site the project, where to send the renewable electrons, economic and workforce development, and the like. Type 3 projects--those that are commercially developed, but mostly for private benefit--are certainly possible, but probably not very realistic or practical.

4. Issues driving the agrivoltaics equity and justice conversation

Unfortunately, no formal metric has yet been developed to evaluate whether an agrivoltaics project is equitable or just, although the ideas in [14] could be used as a starting point. Until recently, much of the conversation around agrivoltaics equity and justice has emanated from the literature pertaining to utility-scale solar farms (i.e., those not paired with agricultural production) [15, 16]. As the agrivoltaics technology and industry mature, the distinctions are becoming clearer. Many of the issues driving today's conversation revolve around what might logically be considered as barriers to more rapid agrivoltaics expansion [17]. By far, the number one category of issues does pertain to land use and/or project siting, followed closely behind by a category that can be labeled as "who gets the benefit of the energy and crops produced?" In addition, there is a whole host of other issues, ranging from finances to agricultural production to power generation to climate change mitigation that are tied up in these two or that somehow reflect the intersection of them. Table 1 contains lists of common themes associated with the two main categories of issues that have been recorded in listening sessions with farmers, county extension agents, and other stakeholders, at conferences and meetings centered on agrivoltaics, or that can be anecdotally found in various online media outlets. While the lists do not result from a scientific study or sample, they can serve as the basis for further research. Other items could obviously be added.

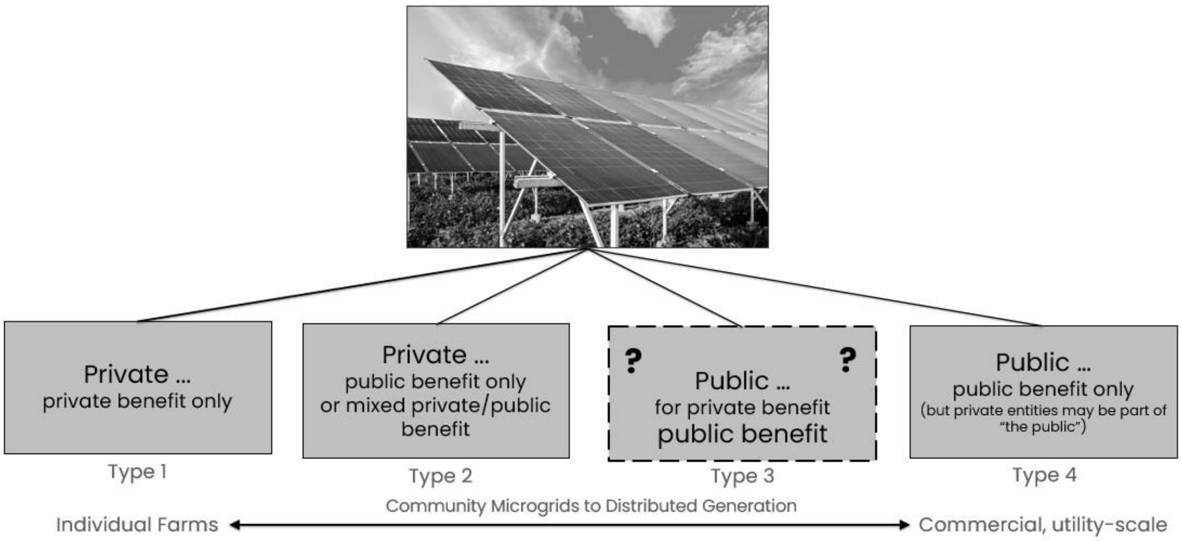

Figure 2. *Agrivoltaics project perspectives (Image credit: iStock/Getty Images).*

In addition to the items listed in Table 1, several other concerns have been raised, some of which are listed in Table 2. The lack of trust and education seem to be the primary underlying factors when considering the contents of Table 2 on whole; both of which could possibly be improved with more farmer-to-farmer interaction.

5. Agrivoltaics adoption paradigms and their relationship to equity and justice

Farmer adoption of agrivoltaics can largely be viewed through the context of risk. Farmers are used to risk in all aspects of their operations, whether it pertains to weather, markets, product prices, labor availability, insurance, or finances. Still, agrivoltaics adoption is a different kind of risk that involves a complete change in operating paradigm. Farmers must take some of their land out of conventional agricultural production (animal grazing or crop production) and put it into energy production, resulting in a potential loss in conventional yield at least at project outset. In addition, there is new and different financial risk, since the cost of deploying solar panels is not insignificant. When farmers make this decision, they are betting on an eventual return on their investment and perhaps a more balanced bottom line, but one that may not be realized immediately. If energy markets tank, or if turns out that the designated land is not close enough

Table 1. *Common themes associated with the two main categories of issues that drive the agrivoltaics equity and justice conversation.*

Land Use / Project Siting	Beneficiaries
• Land leasing vs ownership, generational lineage, retirement, etc.	• Have all the stakeholders been identified, and are they engaged in the planning / development?
• Don’t demonize people for being attached to their land.	• Have priorities, lived experiences, and vulnerabilities of surrounding residents been considered?
• Don’t co-opt the most precious land – land that has been grazed / farmed for generations.	• Where do the electrons go? Does the local community get directed access to renewable energy generation?
• Farmland preservation – if you’re not planning wheat, alfalfa, or beets, you’re not farming!	• Markets for locally sourced produce / crops? Jobs? How many jobs? Are they “good” jobs?
• Proximity to existing transmission infrastructure (or will it need to be constructed, possibly infringing on the land / homes of other individuals?).	• How long will the facilities last? Component damage, waste, and end-of-life management?
• Is the environmental / ecological disturbance minimized? Loss of natural beauty? Water runoff?	• How and to whom is the tax revenue distributed? Property rights vs public good.
• Protected areas and established wetlands are excluded? Cultural / heritage sites?	• Is property value increased? Is air quality improved?
• Land-use competition and zoning standards are primary barriers. Hence, acceptance of agrivoltaics is geocentric (spatial).	• Is the overall livelihood of farmers / ranchers enhanced? Or are utility companies the main beneficiaries?
• Yield reduction.	• How are tenant farmers and migrant workers impacted with re-orientation of land use?

to existing grid infrastructure, or if the county denies the necessary permits, or if any number of other negative situations are realized, then there is the real potential for failure. Further, once the decision is made, the farmer must commit to this operational change for a relatively long period of time, and conditions which may be regarded as favorable at first are not guaranteed to persist. For these and a myriad of other risk-related reasons, some farmers, which are normally a conservative lot, continue to be reticent to talk about adopting agrivoltaics until the technology achieves greater maturity.

Building on the information presented in [18], the sentiments of the farming community regarding agrivoltaics adoption can be grouped into three categories, each one fostering its own equity and justice issues. The first category has to do with *conflict* and is mostly seated in land use concerns. Farmers and other stakeholders with this viewpoint consider energy production to be in conflict or competition with agriculture and are generally opposed to the idea. The second group of individuals views agrivoltaics as a *synergistic* proposition in which energy and agriculture are co-located for dual land use purposes. Those who hold this position see agrivoltaics as a means to optimize both energy and agricultural production, thereby increasing the viability of their overall operations. On the whole, this is a more positive sentiment, but there are still equity and justice issues that are tied to the way in which these individuals approach community engagement and involvement. The third group of individuals views agrivoltaics as a *compromise* that promotes farm and agricultural land preservation. Such individuals may be faced with declining revenue and profit, leading to potential loss of their homes and livelihoods, and they regard agrivoltaics as a way to remain on their land.

Table 2. *Other stakeholder voices and concerns.*

- Will I have the same profit-sharing opportunities as everyone else?
- What about insurance? Are my costs likely to go up or down because I add solar panels?
- It seems as though there is some competition between energy production and crop production. Won't all the profits go to the "big guys?"
- I have a Bison production facility, but our utility company wants to deploy a large-scale agrivoltaics-facilitated beef and sheep operation close by. What protections do I have regarding virus contamination?
- Putting solar panels on our farms is just the first step on a very slippery slope. The next thing you know, they will be forcing us to use electric tractors, and we sure do not want to do that.
- My neighbor has a moderate-sized agrivoltaics "farm." Since she has redeveloped her land, I am more concerned about erosion and water runoff. Does the county have any restrictions about this?
- Why are the permitting regulations one county over so different than those where I live?
- On the one hand, I like the flexibility that agrivoltaics provides in terms of economic stability; but on the other hand, solar panels are fixed infrastructure, and I am committing my land to that particular usage for a long time, limiting my agricultural flexibility over the long haul.
- Will I be forced to sell my crops to certain outlets? Will I be forced to hire certain workers?
- Honestly, I am afraid to commit my land to solar panels. I do not know how long they will last; and even if they do, at some point they will have to be maintained, replaced, and/or removed. Wouldn't that involve potential soil contamination, or even the use of more pesticides and cleaning chemicals?
- Will I have access to the same financing terms as the guy down the road?
- Can I run my own farm off the power I generate? What are the requirements of selling power to the grid? How much can I use before I start selling it to the grid? Can I share with my neighbor first?
- I live in a very rural community. But, like all communities, we have schools to fund, roads to keep up, etc. If we commit a large portion of our county's land to agrivoltaics, will there be more taxes? And if so, will the tax revenue come back to us?
- Was our community asked what crops they would prefer to see grown with agrivoltaics?

There is yet another viewpoint (somewhat akin to the third sentiment described above) that follows the ideas presented in [19]. In this scenario, agrivoltaics is regarded as a "just transition" pathway for the agricultural community; i.e., in the face of farm fragmentation, an aging farmer/rancher population, de-population of rural communities, and the transition of farmland acreage to peri-urban development, agrivoltaics may serve as the basis for a new vision about what rural life and rural communities can be.

Additional stakeholder perceptions and considerations about agrivoltaics adoption and deployment that directly influence the agrivoltaics equity and justice conversation are presented in [20, 21]. While all stakeholder concerns should obviously be considered, the following three expressions help to summarize the status of equity and justice around agrivoltaics today:

- Agrivoltaics should not simply be viewed as a “techno-fix” to land-use tradeoffs and stakeholder concerns.
- Dual land use does not *de facto* reduce opposition to, or promote acceptance of, solar power.
- Robust stakeholder collaboration and public engagement is required to tailor benefits to specific socioeconomic contexts and build trust so that benefits and drawbacks can be equitably distributed.

6. Equity and justice associated with non-rural agrivoltaics deployment

While the foregoing discussion suggests that agrivoltaics may be more typically viewed as a rural venture having rural equity and justice implications, other scenarios incorporating this technology should not be overlooked. As sources of locally produced renewable energy and local-sourced food supplies, agrivoltaics can also be deployed in environments that are more urban or quasi-urban, although the project scale and footprint may be smaller than in rural settings, simply due to space limitations and/or the availability of land. As such, agrivoltaics is highly adaptable to community garden settings in urban food deserts, as the focal point of power-generating microgrids [22], on small urban/backyard farms (e.g., an acre/hectare or less), on greenhouses that produce niche vegetables and flowers, or in rooftop farming situations [23]. A different, perhaps more nuanced, set of equity and justice considerations is associated with each of these scenarios (they are obviously mostly restricted to plant/crop production), and those considerations are likely to be different from the ones encountered in rural deployments. Questions about community engagement and who constitutes the community, space/noise/visibility infringement, commercial and residential development, water conservation, who gets access to the renewable electrons, and who gets to “farm” are exacerbated, for example, in smaller urban areas that are more densely populated. Overall system cost, the availability of financing, ongoing operations and maintenance, insurance, and decisions about who pays also get spotlighted more quickly in these kinds of environments. Public assistance and government incentives can make urban agrivoltaics projects more attractive, but then there are issues around siting, as well as who gets the incentives and for how long. Despite these perceived hurdles, urban agrivoltaics is likely to expand in the coming years, again presenting the industry with an excellent opportunity to promote equity on the front end of this maturing industry.

7. Conclusion

Equity and justice are important concepts to be addressed across the entire energy landscape. Although somewhat late in evolving, politicians, industry representatives, local/regional government representatives, and others now more fully embrace the recognition that expansion of energy technologies and infrastructure has not always been equitable, just, and fair. In this regard, agrivoltaics, as an emerging industry segment, has the singular opportunity to serve as an exemplar for the incorporation of equity and justice throughout the energy transition. To be successful, ecological sustainability, financial sustainability, and social "fit" must remain the guiding principles. Agrivoltaics cannot be viewed simply as an all-in-one solution with which to optimize rural land use. It must be approached as an integrated, collaborative venture that brings communities, developers, regulators, financiers, and individual producers together for the common good of enhancing livelihoods, minimizing the impacts of climate change, expanding energy access, and maximizing food security.

Data availability statement

No physical data or information were involved in the formulation of this presentation other than the textual content of Tables 1 and 2.

Author contributions

Coburn, T.: Supervision, *Writing – Original, Review & Editing*, *Conceptualization* - T. Coburn provided leadership and supervision throughout preparation of the manuscript, contributed to the original draft, and critically reviewed and edited the manuscript.

Conrad, S.: *Conceptualization, Writing – Review & Editing* - S. Conrad contributed to the conceptualization of the research, and critically reviewed and edited the manuscript.

Bradley, T.: *Conceptualization*, *Resources, Writing - Review & Editing* - T. Bradley contributed to the conceptualization of the research, supporting resources for the investigation, and critically reviewed and edited the manuscript.

Lynch, A.: *Conceptualization, Writing – Review & Editing* – The paper borrows from some of the original content prepared by A. Lynch for a graduate course report on the spatial nature of agrivoltaics, directed by T. Coburn.

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Competing interests

The authors declare that they have no competing interests.

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