An Examination of Farmer Perceptions, Social Acceptance, and the Disruptive Potential of Agrivoltaics in Northwest India

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Abstract

Agrivoltaics, the innovative combination of solar energy with agriculture, are theorised to provide holistic benefits across the food-energy-water nexus and address rising concerns of land competition within energy transitions. Across various feasibility studies, there are noted potential socioeconomic benefits of agrivoltaics, such as increased dual- income streams for farmers and energy security. However, due to agrivoltaics' nascency, there is limited research examining community perceptions and lived experiences outside of the Global North. India is an early leader in agrivoltaics installations in Asia; however these sites are predominantly demonstration, research, or pilot sites and no specific policy or regulation has been introduced. Despite India's semi-arid northwestern states being theorised to provide opportunities for agrivoltaics given appropriate policy, a history of land dispossession and marginalisation from renewable energy development contributes to distrust among farming communities. Further, the small-scale agricultural environment prominent in the sub-continent emphasises a requirement for further technological innovation to adapt agrivoltaics to a new context.

A combination of desk-based and field research speaking with experts, community organisers, and farmers in Delhi, Haryana, and Maharashtra contribute to a greater understanding of the prospects of agrivoltaics in India and potentially other Global South contexts. Employing social acceptance, energy justice, and disruptive innovation perspectives, this thesis will evaluate how agrivoltaics and decentralised solar are framed in national publications in comparison to implementation strategies, the existence of an enabling environment, and future pathways for agrivoltaics scale-out in India. These factors engender greater insight into social acceptance of agrivoltaics in South Asia, as well as illustrating the technology's potential in small-scale, rural, or non-traditional settings. This thesis advances agrivoltaics scholarship through the examination of stakeholder and farmer perceptions of the technology in India, while also illustrating the importance of flexibility and experimentation to foster just energy transitions among vulnerable populations.

Author's Declaration

I declare that this thesis is a presentation of original work, and I am the sole author. This work has not previously been presented for a degree or other qualification at this University or elsewhere. All sources are acknowledged as references.

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Chapter 1: Introducing Agrivoltaics and the Indian Renewable Energy Regime

1.1 Introduction

Agrivoltaics have emerged as an innovative response to a rise in exacerbated and compounded climate change impacts, from droughts and diminishing pollinator populations reducing crop production (Graham et al., 2021) to conflict over whether to install solar energy to combat these effects at the expense of open land (Adeh et al., 2019). While still a nascent technology, scholars argue that agrivoltaics systems have the potential to alleviate some, if not all, of these concerns while potentially providing significant socio-economic benefits, such as contributing to dual-income streams for farmers and energy security (Gomez-Casanovas et al., 2023; Schindele, 2021a). While the promise of these benefits remains up for debate while the body of research continues to grow, the technology's rise in popularity in Western Europe, North America, and Asia represent new opportunities to explore its potential globally.

Agricultural lands, including both those used for food production and grazing, make up one-third of the total available land and are deemed increasingly vulnerable to climate change (Gomez-Casanovas et al., 2023). Increased incidence of flood, drought, extreme temperatures, and unpredictable weather have contributed to global agricultural vulnerability (Jatav et al., 2024; Lynch et al., 2021; Prakash, 2022). Further, the global population is expected to increase by three billion people by 2050, with 90% of this three billion from emerging economies who will be reliant on existing land and resources for food, livelihood, and well-being (Srinivasa Rao et al., 2019). Already increasingly water intensive, the agricultural sector is expected to experience severe productivity loss as escalating climate change impacts continue to constrain water availability worldwide (Gomez-Casanovas et al., 2023; Khangura et al., 2023). Scholars and policymakers alike propose renewable energy as key climate change mitigation and energy poverty alleviation strategies, however, many interventions remain resource intensive due to material extraction, manufacturing, and energy production, while also competing for space with agriculture and undeveloped land (Mulvaney, 2017).

Agrivoltaics, the innovative combination of solar energy with agriculture, horticulture, and/or livestock grazing, is theorised to provide holistic benefits across the food-energy-water nexus and may act as a climate-mitigating intervention (Barron-Gafford et al., 2019). Emerging research indicates that the technology is the most effective in semi-arid and arid regions due to theorised benefits, which include increased water and energy efficiency, protective shade for crops, and reduction in land competition (Barron-Gafford et al., 2019; Chel & Kaushik, 2011; Galan, 2022). Across various feasibility studies, there are noted potential socioeconomic benefits of agrivoltaics as well, such as increased income for farmers and energy security (Chandra Giri & Chandra Mohanty, 2022; Galan, 2022; Trommsdorff, Vorast, et al., 2022). However, the specific regional climate, ecology, and social acceptance for solar energy combine to shape the pathways towards its wider adoption (Brudermann et al., 2013). There is limited but growing case study research examining these pathways. Specifically, the examination of community and farmer perceptions based on lived experiences with agrivoltaics beyond feasibility studies have been the focus of limited research outside of the Global North (Kumar et al., 2024; Mahto et al., 2021).

India, an emerging global leader in agrivoltaics development research, has implemented numerous pilot projects in partnership with various universities and research institutions, with more systems being implemented by farmers with the financial and experiential capacity to do so across the country (Pulipaka et al., 2023). Due to the semi-arid climate of the northwestern states of India and the increased water scarcity affecting its agricultural sector (Jadhav, 2023), scholars such as Mahto et al (2021) theorise that agrivoltaics will be a successful intervention given appropriate policy is developed and implemented. However, a long history of dispossession and marginalisation from decision-making in renewable energy developments has contributed to distrust among various communities (Ghosh et al., 2023; Lakhanpal, 2019; Stock, 2021). This necessitates further in-depth understanding of community perceptions, conditions of acceptability, and best practices, based on lived experiences with agrivoltaics in India.

Desk-based and field research in Delhi and Haryana undertaken in partnership with the Indian Council for Agricultural Research – Indian Agricultural Research Institute (ICAR-IARI) and World Agroforestry CIFOR-ICRAF Asia have informed this Doctoral Thesis' contribution to a broader understanding of emerging best practices for and feasibility of agrivoltaics implementation, especially in emerging economy contexts. Desk-based research involved a comprehensive literature review and document analyses to provide crucial contextual and conceptual background and demonstrate existing stakeholder framings of agrivoltaics in India, respectively. Desk-based research also involved virtual semi-structured interviews with stakeholders based in India via Zoom. The field research was conducted in New Delhi, the Delhi Greenbelt, and Haryana and included semi-structured interviews with experts and farmers who participate in agrivoltaics and decentralised solar schemes. The interviews highlighted drivers of engagement, barriers to and conditions to be met to encourage adoption, and localised community-focused configurations.

1.1.1. Research Aim and Questions:

The overarching aim of this thesis is to understand farmer and other stakeholder perceptions of and lived experiences with agrivoltaics in India, a niche that has not yet been discussed at length in research. To this end, social acceptance, disruptive innovation, and energy justice perspectives are utilised to gain greater insight into the emerging and evolving perceptions of agrivoltaics, as well as the technology's potential in South Asia. This thesis will contribute to the growing body of agrivoltaics scholarship through this analysis, while also illustrating the importance of knowledge exchange, flexibility in definitions and socio-technical configurations, and experimentation to foster just energy transitions among vulnerable, rural, or decentralised populations.

This thesis will focus on the perceptions of national, regional, academic, and local stakeholders involved in agrivoltaics and decentralised solar in India to address the following research questions:

1. How are agrivoltaics presented in policy and what are the implications for the development of an enabling environment for agrivoltaics in India?
2. What are the drivers, barriers, and opportunities associated with agrivoltaics' development?
3. In what ways do Indian farmers influence, inform, and disrupt the perceptions, innovation, and implementation of agrivoltaics?

The novelty of this research is two-fold. First, it will evaluate stakeholder perceptions of agrivoltaics based on practical experiences with agrivoltaics and decentralised solar policy, development processes, and long-term implementation, filling a gap in the current scholarship evaluating perceptions based on lived experiences globally but most notably in South Asia, as well as introducing farmer-led approaches to agrivoltaics. Second, this research applies an analytical framework that not only investigates social acceptance based on lived experiences pre- and post-installation but also examines agrivoltaics through disruptive innovation and energy justice perspectives. In conducting this research, I hope to contribute to rapidly growing body of agrivoltaics scholarship and analyse stakeholder perceptions and future avenues for equitable scale-out of agrivoltaics within an Indian context.

As a rapidly developing economy, a case study of India offers a unique perspective on renewable energy and agrivoltaics implementation informed by exponential growth and consequent dispossession (Levien, 2018; Worringham, 2021). While this case study is focussed primarily on northwestern India, notwithstanding the diversity of climate, landscape, and sociopolitical context across the subcontinent, this research will nevertheless contribute to a greater understanding of social acceptance and feasibility of agrivoltaics in India. Furthermore, farmers have been discussed in literature as important stakeholders throughout decision-making processes, however their innovative and small-scale configurations have been little studied in this field. Thus, overarching these objectives that contribute toward addressing a gap in the current body of agrivoltaics literature is the discussion of future pathways of agrivoltaics uptake in rural, small-scale, and often decentralised conditions in the Global South.

An analytical framework informed by social acceptance, disruptive innovation, and energy and restorative justice perspectives will be employed. Utilising this framework, I will argue that Indian farmers' capacities for innovation, despite the lack of specific agrivoltaics policy, regulation, and enabling environment, has the potential to inform a unique roadmap for future and, even decentralised, agrivoltaics development. A discussion of Indian governance structures, electrification, and the renewable energy niche, including the introduction of agrivoltaics, will provide crucial contextual background for this research. First, this chapter will briefly introduce India's governance structures, followed by its historical electrification efforts from colonial to postcolonial eras, roughly from 1800 to modern day, and conclude with a discussion of the current state of the subcontinent's renewable energy transition efforts. This chapter will continue by introducing existing research on agrivoltaics, highlighting its positioning at the centre of the food-energy-water nexus and facilitatory potential for regenerative agriculture. This introductory chapter will conclude with an overview of the thesis and how the thesis will address the research objectives.

1.2 India: A Contextual Background

India, as the world's largest democracy, has implemented significant energy and electrification policy over more than a half century since independence in 1947. From 190 years of varying degrees of British colonial rule, trade controls by the British East India Company from 1757, direct control by the British Raj from 1858, to the modern day, India's electrification has been shaped by complex sociopolitical interactions (Banerjee-Dube, 2015; Kale, 2014). These controls have shaped modern India's government structure, from influencing its parliamentary nature and establishment of free press to the perpetuation of class structures (Tharoor, 2018). Thus, it is impossible to separate India's current government from its colonial history and the sociopolitical influence that history has on the development of current energy infrastructures and governance. Thus, it will be imperative to provide an overview of India's governance structure to contextualise the current state of solar energy and agrivoltaics policy and development.

1.2.1 Government Structure of India

India's seat of government is based in New Delhi, the capital within the state of Delhi in the predominantly Hindi-speaking Northwestern region of India. Rajasthan and Gujarat borders on the west, Haryana and Punjab to the north, and Uttar Pradesh to the east. The area of study for this thesis includes Delhi and Haryana (see Figure 1). While the central government follows a parliamentary system, the term federal is used because the power devolution to the 28 individual State and 8 Union Territory governments more closely resembles systems such as those in countries like the United States (Kale, 2014). Union Territories include island chains to the southwest and southeast as well as large metropolitan areas, including New Delhi. The Government of India describes itself as 'a sovereign socialist secular democratic republic with a parliamentary […] government [which] is federal in structure with unitary features' (Government of India, 2023). The current parliamentary system is modelled after the British Westminster system and comprises approximately 54 ministries, from the Office of the Prime Minister to the Ministry of New and Renewable Energy (MNRE).

[Figure 1: Map of Modern India, including disputed region with Pakistan and China of Jammu and Kashmir]

The British East India Company initiated colonial rule in 1757 to participate in global textile trade following dismissal from other European powers in Asia at the time (Roy et al., 2022). Initial trade agreements with the Mughal Empire progressed to the establishment of outposts, the annexation of territory along the western coast, and finally the overthrow of the Mughals to establish the British Raj in 1858 (Tharoor, 2018). By the establishment of the Raj, the subcontinent was under either direct or indirect rule, wherein several Princely States in the North and Northeast were allowed to persist (Kale, 2014). At its height, Colonial India covered the entirety of what is modern India but also included modern Pakistan and Bangladesh, and parts of Myanmar (Banerjee-Dube, 2015). Decades of resource and human capital exploitation and resource extraction to fund exorbitant Raj governmental salaries, reduced India from one of the wealthiest populations in the 17th century to one of the poorest in the 19th century (Tharoor, 2018). Further, the reinforcement and exacerbation of caste, religious, and class structures by the Raj through employment and educational restrictions widened the gap between the ultra-wealthy and poorest communities (Tharoor, 2018). Various rebellions and independence movements, including the anti-colonialist Indian nationalist and civil disobedience movements of Jawaharlal Nehru and Mahatma Gandhi, defined the final decades of British colonial rule. In 1947, ideological conflict pertaining to the future of India's governance complicated Independence. Over decades, the Raj manufactured cultural, linguistic, and religious conflict between Hindu and Muslim populations by restricting or permitting educational, employment, and other resource accessibility opportunities in equal measure (A. Roy, 2024). This tension impacted cooperative efforts between Nehru's Hindu-led Congress Party and Mohammad Ali Jinnah's Muslim League, and exacerbated by conflicting ideas of postcolonial governance, British reluctance, and India's role in the Second World War, ultimately resulted in the abrupt Partition of India and Pakistan following independence in August 1947 (Roy, 2014; Tharoor, 2018; Phillips & Wainwright, 2025). The Partition was one of the most significant and deadly costs of colonial dissolution, which resulted in large-scale loss of life and forced migration of both Muslims and Hindus in northern India and southern Pakistan, of which sociopolitical ramifications are still felt today (Banerjee-Dube, 2015; Roy, 2024a).

The current modern state system in place today is partially influenced by cultural and linguistic regions formerly belonging to the more than 500 princely states that existed prior to the colonisation of India and more arbitrary colonial delineations (Banerjee-Dube, 2015). In the decades following Independence in 1947, all princely states were gradually absorbed by the corresponding federal states established by the departing colonial government. By the late 20th century, only federal states and union territories existed in what is now modern India (Banerjee-Dube, 2015).

India's colonial history, including the exacerbated class structures and manufactured conflict between the Hindu and Muslim populations by the British that ultimately led to and continue long after the Partition, influence governance and resource accessibility (Chacko, 2019). This is evidenced by the rise of Narendra Modi's Hindu-Nationalist (Hindutva) Bharatiya Janata Party (BJP) and the restrictive access to electricity, communication, food, and other resources to majority-Muslim and other non-Hindu communities, especially in the Northern states of Jammu and Kashmir (Roy, 2024a; Bhatia, 2024). While Hindutva's influence on energy generation was beyond the scope of this thesis, India's wealth and resource access gaps result, in part, from its colonial-era policies. This socioeconomic divide ultimately affects access to and participation in electrification and the energy transition.

1.2.2. Electrification of India from Colonial to Postcolonial Period

The consequences of colonial rule have influenced India's political economy of development and infrastructure provision, either from influence of colonial-era government regulations or infrastructural frameworks established in the colonial era and thus continue to disenfranchise regions or communities deemed unimportant in that era (Roy, 2024a). However, not all consequences of colonial rule were as immediately damaging or easily identified. Much of India's government system is designed after the British parliamentary system because of its colonial legacy and built on the framework established by the colonial government (Kale, 2014; Joseph, 2010). Thus, it is this structural history that has engendered the current uneven development structure of state electricity distribution, and its consequent impacts on renewable energy deployment, today.

For instance, Indian members of various British Raj Ministries in the 1930s planned to enhance rural development through increased connectivity by railway and electrification along pre-established and primarily commercial railway lines to facilitate modernity (Kale, 2014). It was argued that if the establishment of a railway system could encourage development, then electrification would facilitate modernity through increased economic development and social well-being (Kale, 2014). Post-Independence, the newly established central government planned to meet this goal.

Several transitional members of the colonial government-turned-independent democratic government were outspoken about the need for a national and rural electrification movement that was spearheaded and controlled by the central government (Kale, 2014). It was argued by various members of Nehru's government that a central, public electrification distribution and transmission policy established by the central government would ensure consistency across state lines, efficient and regulated access to electricity, while also generating essential rural development (Kale, 2014; Parjal & Banerjee, 2014). However, in the years following World War II and the beginnings of the Cold War, the idea of a nationally controlled, socialist policy was unappealing. In addition, this notion of a nationally regulated energy system was originally based on the much-smaller United Kingdom, which achieved electrification through one overarching, national policy. In contrast, India constituted a much larger geographical space with diverse landscapes and quick, efficient electrification could not occur on the same scale or pace (Kale, 2014). It was for these reasons that the process of electrification was given to the state governments and thus resulting in the uneven development and electrification experienced today (Singh, 2022).

States that were centres of industry, including the agricultural-industrial sector, in the colonial era had higher capacity to build the appropriate infrastructure for electrification (Kale, 2014). Whereas less industrialised states, such as those in the south and east of the country, were targeted for their natural resource deposits and thus did not have similar access or capabilities to develop in a similar manner (Tharoor, 2018). Simultaneously, state governments established their own State Electricity Boards (SEBs) that regulated where transmission and distribution infrastructure was located, how the electricity was distributed, and how the constituents were tariffed (Kale, 2014). Ultimately, different states prioritised different aspects of the modernisation efforts, disregarded many rural communities, and encompassed varying degrees of mismanagement including the use of substandard materials and frequent underreporting of electricity provided and payments received (Kale, 2014; Grover & Chandra, 2006).

As the mismanagement of the 1960s and 70s grew untenable, , the electricity generation industry slowly privatised (Parjal & Banerjee, 2014). This shift allowed for private companies to take over where the SEBs had failed and control decision-making as to where rural electrification should continue (Kale, 2014). For a time, this was a successful policy change as many of the state utilities emerged from bankruptcy. However, due to the capitalist nature of these private companies, distribution lines continued to bypass rural communities with little to no economic viability (Kale, 2014; Galan, 2022). Thus, early electrification in India perpetuated the colonial pattern of prioritising industrial centres and large agricultural plantations owned by wealthy landowners. This policy only further entrenched the uneven development and unequal access to electricity in rural India, as regions with high economic growth and viability were prioritised and regions that did not, were overlooked. Thus, largely poorer, lower caste, and Adivasi (indigenous) communities remained unable to access electricity development initiatives (Sareen & Kale, 2018).

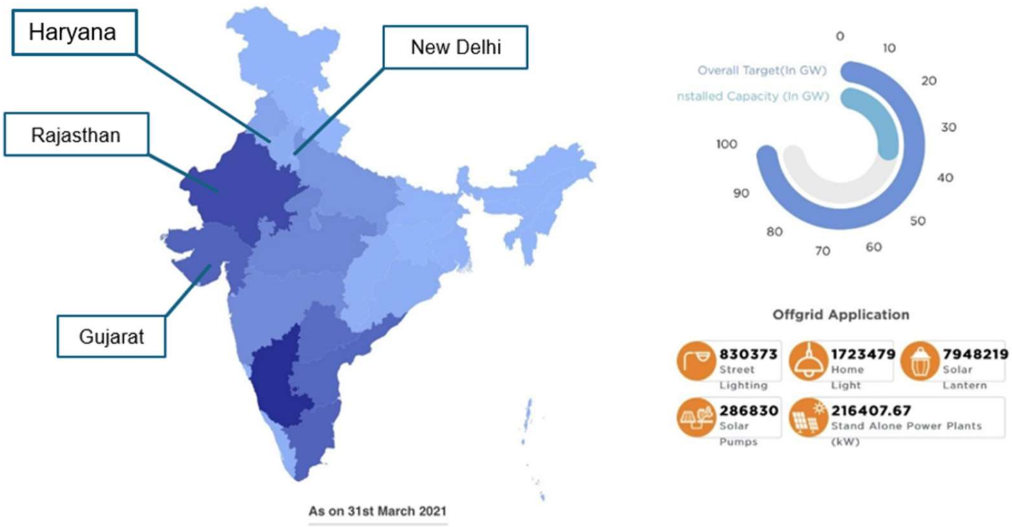
Due in large part to rural farmer mobilisation nationwide in protest of this privatisation, there was a push for public utilities once more in the late 20th century (Kale, 2014). While the opportunity for a national policy as envisioned post-independence had passed, a compromise was reached between private firms and public utilities, resulting in modern distribution companies, known colloquially (and will be referred to in this thesis) as discoms. This restructuring, codified in The Electricity Act of 2003, aimed to ensure transparency, 'rational' pricing, and the 'promotion of efficient and environmentally benign' policies (GOI, 2003). The current institutional and regulatory structure of India's energy sector now comprises of a mix of private and publicly owned regulatory bodies. At the national level, central governmental ministries, including the Ministry of New and Renewable Energy (MNRE) and the Ministry of Power (MoP) oversee the development and promotion of alternative and renewable energy technologies and the electricity sector and policy implementation, respectively (Galan, 2022). In addition, the Indian Renewable Energy Development Agency (IREDA) is responsible for the financing of off-grid and renewable energy projects nationwide. At the state level, independent state electricity regulatory commissions (SERCs) regulate the energy sector; privately-owned distribution companies (discoms) or state electricity boards (SEBs) oversee renewable energy developments (Galan, 2022). And finally, there are state-level agencies and 'nodal institutions' that promote renewable energy and off-grid electrification (Galan, 2022: 1113). This overview of the electricity regulatory structure exemplifies the complex network of institutions that are responsible for electricity access, infrastructure development, financing, and even promotion of renewable energy technologies.

Thus, current national efforts to improve widespread electrification remain a significant challenge regarding how to effectively connect the existing amalgamation of diverse infrastructure and regulatory systems established by states decades prior. The combination of this uneven development caused by rapid electrification in some regions and stunted electrification in others, and the modern hybrid system of energy regulation presents significant ramifications for energy transitions, notably renewable energy implementation and innovation (Sareen & Kale, 2018). India's recent political shift towards market-focused policy has corresponded with a rise in Hindu Nationalism, known as Hindutva (Chacko, 2019). While this ideology does influence renewable energy policy, especially in the context of non-Hindu communities either seeking to become involved in the transition or protest exploitative developments (Singh, 2024; Menon, 2022), it was beyond the scope of this thesis to investigate Hindutva's influence on agrivoltiacs' future in India. In understanding of the historical context of India's electrification, this chapter will conclude with a discussion of the current state of solar energy in India, followed by an overview of the thesis.

1.2.4. Status of Solar Energy in India

Despite challenges facing electrification efforts, India is an emerging centre for renewable energy development. The International Solar Alliance (ISA), launched by India and France at the 2015 Conference of Parties (COP21) with its secretariat in India, was established to promote solar electricity in the 'sunshine belt' regions between the Tropics of Capricorn and Cancer, including several in Africa and Southeast Asia (Shidore & Busby, 2019: 1). This in addition to ongoing partnerships with Germany through the Indo-German Energy Forum and the United Kingdom through the One Sun One World One Grid Initiative suggests India's geopolitical influence in global renewable energy development. At the 2021 Glasgow Conference of Parties (COP26), the Government of India has announced its plan to mobilise renewable energy and to convert 50% of India's electricity generation to renewable energy and reach net-zero emissions by 2070 (Birol & Kant, 2022). Indian Prime Minister Narendra Modi has also raised the national goal of renewable energy development from 100 gigawatts (GW) to 500 gigawatts (GW) by 2030 (Birol & Kant, 2022). India's renewable energy capacity was 33.8 GW in 2021, with 66% sourced from wind and 4.6% from solar energy (Government of India, 2024a). Since then, a further 45 solar parks totalling 37 GW have been approved, including the 'world's largest' renewable energy park encompassing a 30GW solar-wind hybrid park in Gujarat (Dey et al., 2022: 6).

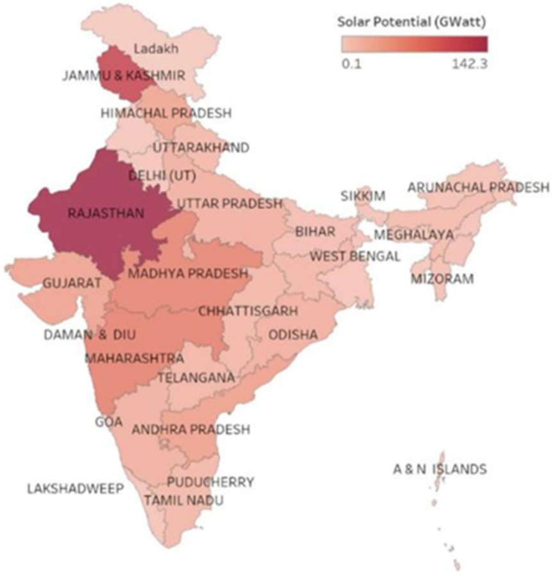
Figure 2, supplied by the Ministry of New and Renewable Energy, illustrates the installed capacity of solar energy as of March 2021. It provides an overview of the state of solar energy distribution nationwide. The highest density of solar installations is in Rajasthan, an arid northwestern state, and Karnataka in the southwest. While Gujarat, the home state of Prime Minister Modi, does not top the list for solar capacity, it was the first state to institute a solar subsidisation programme in 2004 through then-Chief Minister Modi (Jaffrelot, 2019). The Ministry of New and Renewable Energy has since updated its reporting of installed capacity, noting that 89.43 GW have been installed as of August 2024 (Government of India, 2024a). Of these installations, 77% (69.19 GW) are attributable to ground-mounted, large-scale solar parks, and only 4% (3.76 GW) constitutes off-grid solar (Government of



India, 2024a).

[Figure 2: Solar Energy Capacity in 2021 (Source: MNRE, 2022)]

Comparatively, a depiction of the solar energy generation potential (Figure 3) provided by the National Institute of Solar Energy (Mahto et al., 2021), indicates that Rajasthan possesses the greatest solar irradiance and thus electricity production. However, Jammu and Kashmir, on the border with Pakistan (and disputed between the two) appears to have the second highest solar irradiance likely due to its Himalayan altitude. In general, the Northwestern and Western states have higher solar generation potential compared to the more tropical Southern and Eastern states.



[Figure 3: Electricity generation potential, as predicted by the National Institute of Solar Energy (NISE), 2021]

Despite significant progress, 64 million people in India lack access to modern energy in 2018 (Galan, 2022). There have been noted concerns over energy accessibility in rural areas, specifically pertaining to electricity accessibility, reliability, and infrastructure management (Khandker et al., 2014). While it is recognised that increased rural electrification engenders socio-economic benefits beyond access to electric appliances, including increased climate resilience in agrarian communities and improved health, these benefits are dependent on electricity reliability, if accessible at all (Malakar, 2018). Without this reliability, household wellbeing and community benefits achieved through rural electrification are detrimentally impacted (Khandker et al., 2014). Nevertheless, the central government's focus on the renewable energy transition remains key in addressing the local, national, and global climate crisis while expanding energy access, and thus should not be discounted.

The introduction of agrivoltaics technology by research institutions and funded by the central government is expected to play a significant role in both the electrification and renewable energy goals (Kumar et al., 2024; Pulipaka et al., 2024). This role may include mitigating the impacts of increasing desertification in the arid and semi-arid Western states by taking advantage of the higher solar generation potential, as well as improving access to the solar energy transition for many rural communities not yet electrified (Barron-Gafford et al., 2019; Gomez-Casanovas et al., 2023). However, the majority of existing agrivoltaics installations contributing to research in India constitute research, pilot, or demonstration sites (Pulipaka et al., 2023). Accordingly, greater attention is needed on the social implications of the technology, globally as well as in India (Trommsdorff, et al., 2022). The following section will introduce agrivoltaics as an emerging innovation theorised to achieve ecosystem, energy, and socioeconomic security.

1.3. This Thesis at a Glance

The aim of this introductory chapter was to provide contextual background on India's history, current political and energy regimes, and agrivoltaics research both globally and within India. It is evident that there are opportunities for agrivoltaics implementation and presents multiple opportunities for innovative configurations addressing rural electrification and community well-being. However, the limited regulation and limited enabling environment may detrimentally impact the feasibility of sustainable and equitable scale-out of agrivoltaics.

Existing agrivoltaics research remains in its nascency, however it is growing in quantity, quality, and discipline exponentially. Nevertheless, scholars have recognised significant gaps in the literature that critically examine the socioeconomic implications and stakeholder perceptions of agrivoltaics installations based on lived experiences with policy implementation, development, and maintenance. As social acceptance and perception evaluation studies emerge, this gap remains most notably in Global South contexts. As such, to contribute to addressing this gap in agrivoltaics research, this thesis will examine the perceptions of agrivoltaics in India, both pre- and post-development, and analyse the potential roadmap for future sustainable and equitable scale-out of the technology.

To this end, this doctoral thesis will continue as follows:

Chapter 2: Agrivoltaics: An Innovative Solar Technology will review the literature on agrivoltaics, examining its theorised holistic environmental and socioeconomic benefits. This chapter will also introduce the current state of agrivoltaics research and development in India.

Chapter 3: Examining Social Acceptance, Disruptive Innovation Potential, and Restorative Energy Justice of Agrivoltaics: An Analytical Framework will discuss the concepts utilised in this study. Concepts such as social acceptance, technological and disruptive innovation, and restorative energy justice will be introduced in this chapter and facilitate the analysis in the chapters that follow.

Chapter 4 will introduce the methodology utilised in this study. Documentation and policy reports will be examined using thematic, narrative, and content analysis to evaluate both how stakeholders frame agrivoltaics and decentralised solar as well as perceive drivers, risks, and benefits of engagement. Unique to this study, semi-structured interviews and photo-visual techniques will be critically evaluated through thematic, narrative, and content analysis to understand farmer perceptions, lived experiences, and prospects of agrivoltaics. Each of these methodologies will contribute to more robust understanding of the innovative potential of agrivoltaics and the technology's role in just transitions in India. This framework will provide a lens through which to examine the implications of agrivoltaics development in India and contribute to the growing body of work on this innovation.

Chapter 5: Presenting Agrivoltaics: Framing Stakeholder Perceptions and Evaluating the Existence of an Enabling Environment will address the first research question of: *How are agrivoltaics presented in policy and what are the implications for the development of an enabling environment for agrivoltaics in India.* Through the analysis of published policy documents and reports on decentralised solar and agrivoltaics, as well as national stakeholder interviews, this chapter argue that there is a disparity between how the technologies are framed by stakeholders and how the policy and technologies are implemented and installed, respectively. This chapter will conclude that while there are opportunities for a sustainable introduction of agrivoltaics in India, there are multiple factors that prevent an enabling environment for widespread accessibility and adoption of the technology.

Chapter 6: Conditional Acceptability of Agrivoltaics: Perceived Barriers, Risks, and Opportunities that Influence Adoption will aim to answer the second research question of: *What are the drivers, barriers, and opportunities associated with agrivoltaics development?* Through the examination of semi-structured interviews with multiple stakeholders, including civil servants, NGO employees, agrivoltaics developers, and farmers, this chapter will compare the differing stakeholder perceptions and examine the conditions under which the average Indian farmer would consider installing an agrivoltaics system. This chapter will argue that while multiple stakeholders have diverse perspectives on agrivoltaics implementation, treating farmers as equal stakeholders throughout the process will likely engender improved perceptions, social acceptance, and adoption.

Chapter 7: Disrupting Agrivoltaics Paradigms: A Roadmap for Development, Implementation, and Innovation in India will aim to answer the third and final research question of: *In what ways do Indian farmers influence, inform, and disrupt the perceptions, innovation, and implementation of agrivoltaics?* Semi-structured interviews, walking interviews, and photo-visual techniques were utilised to understand the lived experiences with agrivoltaics and decentralised solar in rural Northwestern India. This chapter will argue that the innovative nature of farmers must play a role in future scale-out to produce a sustainable and just transition to agrivoltaics in India.

Chapter 8: Conclusion: Community Re-Powering through Adaptive Agrivoltaics and Avenues for Future Research will summarise and synthesise the arguments made in the preceding chapters and finally, present the concluding remarks of this thesis. This chapter will also discuss the limitations of this study, including this researcher's positionality, and introduce opportunities for future research.

Chapter 2: Agrivoltaics: An Innovative Solar Technology

2.1 Agrivoltaics: An Emerging Solar and Agriculture Co-Located Technology

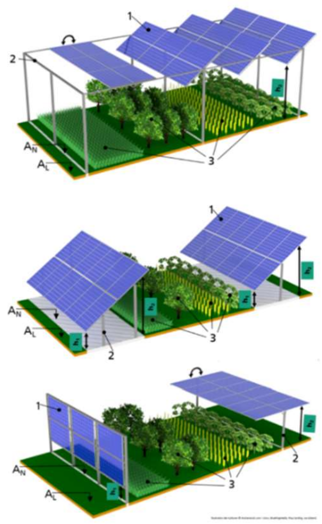
Solar energy is an important source of renewable energy, component in the energy transition, and climate mitigation strategy (Mulvaney, 2017). In some countries, it has surpassed traditional fossil fuel developments and is cheaper in certain scenarios, including both commercial-scale developments and residential rooftop arrays in the long-term (Mulvaney, 2017). Conventional ground-mounted solar energy systems can be arranged on large areas of flat, open land, however, in recent years, concerns over land competition with agriculture, ecological conservation, and landscape preservation have become more vocal (Martinez, 2020; Pascaris et al., 2020). Thus, the transmutable and scalable nature of solar energy has garnered more attention by researchers, developers, and politicians (Adeh et al., 2019; Muraleedharan Pillai et al., 2020).

In addition to the well-known commercial and residential rooftop capabilities of solar, research investigating and policymaking in support of community solar configurations have increased in recent years. Community solar can be conceptualised in multiple ways, including micro-grids, or installed in a central community area or community hub such as schools, town halls, or religious buildings, and consist of multiple ownership models to improve accessibility (Bilich et al., 2024; Joshi & Yenneti, 2020). It is also characterised by a communal ownership model wherein consumers of the energy produced from the system own a stake in its development (Hoicka et al., 2021). Community solar and other inventive configurations are gaining momentum, however, traditional ground-mounted solar remains the most prominent configuration globally (Mulvaney, 2017).

Further, despite the benefits of an accessible and scalable renewable energy technology such as solar, there remain significant challenges with its implementation and regulation that are influencing opposition to solar technologies, most notably in the Global South (Kumar et al., 2021). These challenges include but are not limited to deforestation and development of natural spaces, disruption of ecosystem services, community dispossession, and prohibitively high upfront costs (Dinesh & Pearce, 2016; Martinez, 2020). Land competition is expected to increase when considering an expected rise in global solar capacity from 385 gigawatts (GW) in 2017 to 8,500 GW in 2050 (Trommsdorff, Vorast, et al., 2022: 1). These concerns highlight the importance of research and sustainable implementation of multi-use solar installations that recognise, address, and potentially even mitigate them. Sacrificing communities and ecosystem health for the purpose of achieving a renewable source of energy is a short-sighted pathway to highlight meeting renewable energy goals that will not result in long-term sustainable development (Hu, 2023). Therefore, a transformative solution that builds upon the existing successes of solar, from its scalable nature to its long-term affordability, to generate a more just and equitable iteration that empowers communities rather than simply powering them should be prioritised.

Agrivoltaics, the combination of solar energy with active agricultural practices has been promoted and argued to be one such innovation (Schindele, 2021; Barron-Gafford et al., 2019). The recent emergence of solar energy co-location strategies and research has grown in interest (Dinesh & Pearce, 2016; Pump et al., 2024). As the field develops, various definitions and identifiers continue to be utilised, varying from dual-use and co-location to 'agri-photovoltaics' (Ketzer, Weinberger, et al., 2020; Worringham, 2021). Ultimately, whilst co-location or dual-use can be used as an umbrella term for multiple innovative solar technologies, which include but are not limited to floating solar or 'floatovoltaics' (Gamarra & Ronk, 2019), solar grazing wherein livestock share the land with the panels (Horowitz et al., 2020), and pollinator-friendly solar (Graham et al., 2021), 'agrivoltaics' has become the most widely utilised term for solar energy co-located with agriculture (Meitzner et al., 2021; Trommsdorff et al., 2023; Widmer et al., 2024).

Drawing from agroforestry and regenerative agricultural practices, agrivoltaics is understood as solar co-located with agriculture and generally involves cultivating crops, pollinator-friendly habitats, or animal grazing under and around the arrays (see Figure 4) (Elevitch et al., 2018). Some analysts also view agrivoltaics as situated at the centre of the food-energy-water (FEW) nexus, in which the systems keep land in continuous use for agriculture and land conservation, generate a cool microclimate under the panels to protect crops against extreme temperatures and improve soil health, and the crops themselves cool the underside of the panels to improve the overall energy efficiency of the system (Barron-Gafford et al., 2019; Jing et al., 2022a). While early definitions of agrivoltaics focused on their technical features, holistic conceptualisations emphasising land productivity both through improved crop yield and socioeconomic and energy security have emerged (Bhandari et al., 2021; Walston et al., 2022).



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A_L = Agriculturally usable area
A_N = Area not usable for agriculture
h_1 = Clearance height below 2.10 m
h_2 = Clearance height above 2.10 m
1 = Examples of solar modules
2 = Mounting structure
3 = Examples of agricultural crops.

[Figure 4: Diagram of different agrivoltaics configurations (Source: Fraunhofer Institute for Solar Energy Systems, 2024)]

Dual-use solar was first introduced as a theoretical concept in 1981 but agrivoltaics was not fully acknowledged as a potential intervention until recently (Abidin et al., 2023; Dinesh & Pearce, 2016). Prior to widespread, global recognition, agrivoltaics configurations have been employed in Japan since 2004, as the country struggled to reconcile energy and food demands on land (Tajima & Iida, 2021; Worringham, 2021). Japan's policy stipulation that no new solar arrays could be installed on barren land and only co-located with another industry, including agriculture, represents one of the first agrivoltaics policies (Tajima & Iida, 2021). This regulatory protection of land and agriculture against industrial development has been adopted and expanded by other countries when introducing agrivoltaics policy, including Germany (Pump et al., 2024), Italy (Potenza et al., 2022), France (Carrausse & Arnauld de Sartre, 2023), Taiwan (Hsiao et al., 2021), the United Kingdom (Garrod et al., 2024), and the United States (Goldberg, 2023; Moore et al., 2022). However, despite agrivoltaics' potential to combat land competition, concerns over the de-prioritisation of agriculture in favour of more lucrative energy production have been recognised both in research and policy. Updated policies have attempted to address these concerns. For instance, Japan has required that rice production under agrivoltaics requires a minimum yield of 80% compared to normal production, and France has stipulated that agriculture must be determined the primary industry and energy production as secondary (Worringham, 2021).

As exacerbated climate impacts affect agricultural production globally, population growth that puts pressure on global resources, and a simultaneous need to transition to renewable energy, innovative, holistic strategies such as agrivoltaics and corresponding regulation grow in importance. While the significance of agrivoltaics' position at the centre of the FEW nexus has the potential to provide environmental, energy, and socioeconomic benefits and justice, the protection of land remains an important attribute cited by policymakers and researchers (Pascaris et al., 2021).

The following section will review the existing research on agrivoltaics, including its positioning within the FEW nexus, regenerative agriculture, and socioeconomic perspectives. Following this review, the current research and regulatory landscape of agrivoltaics in India, the focus of this thesis, will be introduced.

2.1.1. Agrivoltaics, the FEW Nexus, and Regenerative Agriculture

Researchers acknowledge that agrivoltaics systems generate a symbiotic system wherein the shade from the panels helps soil retain moisture throughout the day reducing water requirements, the panels provide shade for crops and farmers in high temperatures, and the crops cool the underside of the panels to improve energy efficiency and lifetime of the panels (Dinesh & Pearce, 2016). Certain agrivoltaics configurations also harvest rainwater for irrigation and panel cleaning, further reducing water requirements for agricultural practices (Barron-Gafford et al., 2019; NREL, 2019.; Gomez-Casanovas et al., 2023). An agrivoltaics system presents opportunities for participating within the renewable energy transition while also preserving and even improving the quality of agricultural land in the process (Elevitch et al., 2018; Gordon et al., 2022; Wagner et al., 2023). Thus, increased awareness of the negative impacts of climate change on the land as well as the global decrease of open, arable land due to overdevelopment and climate has encouraged research into agrivoltaics as a viable, innovative strategy towards addressing the renewable energy transition, agricultural resource security, and land conservation.

The FEW nexus is a method of envisioning the interconnected nature of our energy systems, from extraction to distribution, concerning both ecosystems and human society (Campana & Lawford, 2022). The agricultural and energy sectors have become increasingly inextricably linked because of historical societal transformations (Singh Somvanshi et al., 2020; Yamauchi, 2007). The term's underlying thinking can be traced back to the United Nations Conference for the Conservation and Utilisation of Resources in 1949 and is utilised in many environmental and geographical fields. It involves meeting the needs of an increasing population through sustainable resource management without imposing adverse or 'deleterious' impacts on resources and environment (Miao & Khanna, 2020). Since the establishment of the FEW Nexus Programme at the United Nations University in 1983, there has been an increased focus in FEW nexus thinking within research (ibid). The term has been utilised across multiple environmental and geographical disciplines, including as a central theory and justification for agrivoltaics research and development (Barron-Gafford et al., 2019).

Globally, both the agricultural and energy sectors are heavily water and land intensive, but with increased technological reliance, energy is now often required in energy aspect of the water supply chain and land requirements for renewable energy production are only expected to grow (Khara & Ghuman, 2023; Zhu et al., 2020). For example, in rural and decentralised regions in India where water access is often dependent on manual labour, but groundwater has severely depleted since the Green Revolution of the 1960s and '70s infrastructural improvements and the introduction of diesel pumps for irrigation are becoming ever more popular (Chowdhury & Mandal, 2021). Overexploitation of groundwater resources from frequent misuse of automatic pumps can result in saltwater intrusion and ground subsistence (Zhu et al., 2020), and concerns over agricultural run-off polluting water supplies remain a global concern (Wydra et al., 2019). Water is also required for many aspects of energy generation, including cooling, maintenance, and cleaning processes (Chowdhury & Mandal, 2021). For solar specifically, a significant amount of water is needed for the cooling and cleaning of the panels to maintain energy efficiency (Mulvaney, 2017). While land requirements for solar energy have decreased with technological improvements, solar is still perceived as detrimentally impacting the landscape

(Bolinger & Bolinger, 2022; Ioannidis & Koutsoyiannis, 2020). Large-scale traditional solar installations continue to have large water and land requirements, resulting in implications for deforestation, erosion, and run-off as well as land competition concerns (Chand et al., 2022; Ravi et al., 2016). In some cases, it is considered more cost-efficient to remove vegetation and tree cover rather than work around or with them when installing solar systems (Miao & Khanna, 2020).

Scholars argue that agrivoltaics have the capacity to address these challenges and achieve the intersection of food, energy, and water sustainability without significant compromise (Barron-Gafford et al., 2019; Schindele et al., 2020). Significant research is being undertaken to examine the configurations that are most effective in meeting this goal. For instance, a study conducted by the National Renewable Energy Laboratory (NREL) in the southwestern United States, found that fruit production was three times greater, water efficiency for tomatoes and jalapenos increased substantially in an agrivoltaics system rather than a control, and that the crops kept the panels approximately 9 degrees Celsius cooler during the day (NREL, 2019).

As with any emerging technology, there are many contradictions in the literature as the research becomes more robust. Despite the early positive results, such as improved panel efficiency due to the crops underneath, often researchers have observed the crops as experiencing growth deficits in the first couple agricultural cycles, posited to be due to farmers adapting to the new configurations and the additional shade (Gomez-Casanovas et al., 2023; Miao & Khanna, 2020). Other studies have found that while crop growth rates underneath the panels may be less compared to traditional agriculture, land productivity can increase by up to 70% and also enhancing farmers' income (Bhandari et al., 2021; Weselek et al., 2021). Although agrivoltaics are more expensive than traditional, ground-mounted solar due to the additional materials required to raise the panels, the improved land use productivity has been noted to increase farmers' incomes by approximately 30% given 'yield losses through shading effects are minimised by the selection of suitable crops' (Weselek et al., 2021: 3). As mentioned above, only a small percentage of crops have been evaluated under agrivoltaics panels and thus this assertion only indicates the potential socioeconomic benefits of these systems. It is also noted that yield decreases in the first years should be expected due to the technology, indicating that agrivoltaics is an entirely new system that requires a learning period not just for the farmers, but developers as well (Agostini et al., 2021). Thus, it is not simply just the combination of solar and agriculture, but rather an innovative, symbiotic system that must work together cohesively.

While these assertions have been predominately limited to feasibility studies, further socio-economic benefits have been theorised in the literature. Most notably, agrivoltaics systems have the capacity to generate dual-income streams as farmers can sell excess electricity produced back to the grid or receive land rent from leasing to developers depending on ownership mechanisms and continue to cultivate their land (Choi et al., 2021). To address land competition fears, researchers recommend taking an 'agro-centric' approach to sustainably integrate renewables into rural communities (Choi et al., 2021: 2). Life cycle analyses have indicated that small-scale agrivoltaics systems have the potential to be economically viable in 'certain configurations' while providing several co-benefits (Ravi et al., 2016: 390). These include contributing to rural electrification efforts, retrofitting diesel energy generation equipment, and providing more stable electricity access for improved education, health services, and gender equality (Choi et al., 2021; Ravi et al., 2016; Walston et al., 2022). While these 'certain configurations' remain unspecified due to assumptions made in the modelling, these studies highlight how stable access to electricity via agrivoltaics may improve overall community wellbeing.

Further, a feasibility study in Niger, in the north African Sahel, points to relative potential benefits but notes that theoretical assumptions established by existing literature are not definitive enough for stakeholders to commit to such technological investments (Bhandari et al., 2021). Combined with concerns over land competition and distrust in renewable energy developers particularly in the Global South, more research is needed on the specific benefits and risks of agrivoltaics implementation in different contexts to improve perceptions. Agrivoltaics have recently been analysed through a social acceptance lens to understand community, farmer, industry, and other stakeholder perceptions of the technology (Pascaris et al., 2020, 2022; Torma & Aschemann-Witzel, 2023). However, much of this body of work involves investigating perceptions pre-installation in North America and Europe. Thus, further analysis of social acceptance of agrivoltaics in other global contexts and based on lived experiences will be required (Bhandari et al., 2021; Galan, 2022). The concept of social acceptance will be further examined in Chapter 3: Examining Social Acceptance, Disruptive Innovation Potential, and Restorative Energy Justice of Agrivoltaics: An Analytical Framework.

Recent research has also drawn from regenerative agriculture perspectives to argue for more holistic understandings of agrivoltaics and potentially improve perceptions among the public (Goldberg, 2023; Sarr et al., 2023). Regenerative agriculture has been referenced since the 1970s but has also experienced a recent 'resurgence of interest' (Giller et al., 2021: 13). The term has multiple definitions but generally refers to agriculture that improves land and soil productivity, encourages 'built-in economic and biological stability', maintains the 'balance' between agricultural practices, environmental services, and community welfare, and 'enables' the sustainable, long-term production of food that is 'healthier' for people, the planet, and its climate (Giller et al., 2021: 14-17). Proponents have advocated that agrivoltaics systems can be adapted to 'suit' regenerative farming practices, including through improved efforts for soil regeneration, water infiltration, and minimised erosion (Kuaban et al., 2023: 3). Solar panels can be integrated into agriculture to act as 'armour' to protect soil from high temperatures and prevent rapid water evaporation, thus further improving the survival rate of healthy bacteria, fungi, and other helpful organisms that contribute to healthy soils and long-term agricultural productivity (Kuaban et al., 2023: 3). Additional studies have found that agrivoltaics systems boost crop productivity in arid and semi-arid areas when compared to traditional agriculture, while others have found notable decreases in productivity (Barron-Gafford et al., 2019; Biró-Varga et al., 2024; Klokov et al., 2023; Trommsdorff et al., 2023).

Regenerative strategies in dual-use agriculture and energy production may also encourage innovative configurations for agrivoltaics, such as community energy projects. Community-owned energy resources can introduce new opportunities, including lowering the investment costs, reducing the financial barriers to entry, and sharing ownership and maintenance responsibilities (McCoy et al., 2021). However, scholars recognise that only limited research has been dedicated to analysing the role of local renewable energy developments in 'supporting medium- to long-term transformation towards multi-functional, diversified, and "resilient" economies', the factors that would enable or prevent communities from engaging in those projects (Berka & Creamer, 2018: 3414), and the trade-offs of and potential for '[hybridised] combinations' of multi-functional energy systems (Bessette et al., 2021; 408; Schelly et al., 2020).

Agrivoltaics' potential as a regenerative agriculture strategy further emphasises the role the technology may have in achieving food, energy, and water security on the same land, optimising land use and reducing land conflict in the process (Sarr et al., 2023). However, due to the relative nascency of agrivoltaics' research, only a small percentage of crops, climate conditions, and socio-technical configurations have been studied in both modelling and real-world scenarios. Thus, there remain significant gaps in the literature that would contribute to a more robust understanding of the impacts and potential of agrivoltaics across multiple social and geographical contexts. For instance, despite a growing pool of crucial work undertaken in South America (Jung et al., 2021), Africa (Cinderby et al., 2024; Macdonald et al., 2022; Randle-Boggis et al., 2021), the Caribbean (Bilich et al., 2024), and Asia (Li et al., 2021; Mahto et al., 2021), the majority of agrivoltaics research has a Global North bias. This bias indicates that most data is skewed towards specific climates, regional regulations, higher levels of economic development, and infrastructure capacity and provision that may not be transferable. Further, despite a recent surge in socioeconomic examinations of agrivoltaics, including on the social perceptions and potential implications, the rapidly growing body of agrivoltaics research has largely focused on technical aspects (Pascaris et al., 2020; Torma & Aschemann-Witzel, 2024). Specifically, while India has been encouraging agrivoltaics research since 2021 and has been filling a gap in research in a Global South context, there has also been limited consideration beyond feasibility scenarios given to the socio-economic impacts of agrivoltaics on the larger agricultural community (Mahto et al., 2021b; Pulipaka et al., 2023; Trommsdorff, Vorast, et al., 2022). These socioeconomic impacts will be discussed in the following section (2.1.2.) in the context of Indian agrivoltaics, and in Chapter 3 to contextualise the examination of social acceptance literature. Further, while the potential for agrivoltaics remains significant, a growing number of analysts have called for additional on-the-ground, practical research in Global South contexts to contribute to a growing global, robust understanding of agrivoltaics and its role in the energy transition, a gap that this thesis contributes to (Sarr et al., 2023; Trommsdorff, Vorast, et al., 2022).

In sum, the existing literature on agrivoltaics has highlighted its potential to reconcile land competition concerns between solar energy and agriculture, as well as its ability to benefit farmers and surrounding communities through the provision of sustainable energy generation. The following section will turn to the current state of agrivoltaics research and emerging policy in India.

2.1.2. Agrivoltaics in India

Despite agrivoltaics' recent emergence as a potential mitigating solution for land competition between renewable energy and agriculture, research in India has surged. This section will provide a comprehensive background on the current state of agrivoltaics research and developments in India as well as review literature on its prospective future.

Approximately 60 percent of India's land is designated agricultural land and 83.4 percent of the total landmass of the subcontinent is 'suitable' for solar with sufficient irradiation levels for efficient energy generation (Mahto et al., 2021b: 5). To address concerns over desertification, drought, and energy insecurity in India, greater attention has been given to agrivoltaics in the subcontinent. In 2022, the first report introducing the existent agrivoltaics pilot projects in India was published by the National Solar Energy Federation of India (NSEFI) and the Indo-German Energy Forum (IGEF) (Pulipaka et al, 2022). This report initially introduced 16 pilot projects ranging in electricity generation capacity and climate, with most projects located in the semi-arid and arid states of Northwestern India. In 2023, this report was rereleased to introduce the 22 operational and further planned pilot agrivoltaics installations (Pulipaka et al., 2023).

While it is significant that India has prioritised agrivoltaics research through the installation of pilot systems in different climates and configurations, scholars acknowledge that there is still no specific policy that regulates agrivoltaics developments in the country (Mahto et al., 2021; Pulipaka et al., 2024; Rahman et al., 2023). As mentioned above, recent trends toward market-focused policy have contributed to systematic changes in land ownership laws and regulatory processes that exclude and dispossess marginalised communities (Dutta & Nielsen, 2021; Singh, 2024b). This trend is not exclusive to conventional solar generation; it is emerging in agrivoltaics discourse as well.

Various financial incentive and subsidy structures exist for ground-mounted solar installations; however, none explicitly include agrivoltaics. The PM-KUSUM Scheme is one of the most prominent national solar incentive policies for farmers in India. The Pradhan Mantri - Kisan Urja Suraksha evam Uthaan Mahabhiyan Scheme, or the Prime Minister's Farmers Energy Security and Upliftment

Campaign, consists of three Components that engender decentralised solar generation capacity (Mehta & Winter, 2022). Component A allows for solar to be developed on land designated for commercial use, however this section also allows for solar facilities to be installed on 'barren' and 'uncultivable' agricultural land (Government of India, 2019: 2; Worringham, 2021). While the current iteration of this policy excludes agrivoltaics on active agricultural land, it is stipulated that 'cultivable land may also be used if the solar plants are set up on stilts where crops can be grown below the stilts and sell RE [renewable energy] power to the Discoms', or energy distribution companies, and the 'farmers can continue to cultivate' underneath (Mehta & Winter, 2022: 5; 163). Components B and C pertain to solar irrigation pumps and qualify for substantial subsidies, whereas solar installations under Component A do not (Government of India, 2019). As Worringham (2021) has discussed in a report investigating the feasibility of agrivoltaics in India, there are opportunities for incentives to evolve as agrivoltaics grows in international research focus and other policies can be adapted to the Indian context. Recommendations for agrivoltaics policy development include the establishment of co-ministerial working groups between the Ministries of New and Renewable Energy and Agriculture and Farmers' Welfare, among others (Worringham, 2021), life cycle policies that regulate subsidisation, ownership, management, and end-of-life processes for farmers (Mahto et al., 2021), and market-oriented business models (Rahman et al., 2023).

While each of these policy recommendations are a good first step toward introducing and regulating agrivoltaics, the fact remains that no policy currently exists. The PM-KUSUM Scheme's non-existent financial subsidisation for the Component best suited for agrivoltaics adoption indicates an administrative preference for market-focused agrivoltaics policy. Current documentation outlining best practices for agrivoltaics implementation frame the technology as an opportunity for capacity building, however, maintain that a market-driven approach to financing is most feasible for uptake (Pulipaka et al., 2024). While Rahman et al. (2023) present business models grounded in equal partnerships between developers, farmers, regulatory bodies, and electricity distribution companies (Discoms) to sustainably implement agrivoltaics, they also acknowledge challenges, including distrust between stakeholders that might impact the equitable implementation of the systems. The lack of specific policy reduces a fair allocation of responsibilities, cooperation over system design, and regulation of land ownership, timely payments, and land and agricultural preservation over energy generation (Rahman et al., 2023). With the current increase in agrivoltaics development and research, interest in the technology is expected to increase (Mahto et al., 2021). However, the current lack of specific policy regulating the adoption and lifetime of the systems may contribute to some of the challenges outlined by Rahman et al. (2023). Further, despite the increased affordability of solar, the upfront and lifetime costs remain significant and well outside the budget of many without subsidisation (NREL, 2021). In comparison, agrivoltaics systems are more expensive than traditional solar and in India, may come with increased associated costs, such as grid-connection or infrastructural improvements, freshwater access for both irrigation and panel cleaning, and maintenance (Rahman et al., 2023; Trommsdorff, Vorast, et al., 2022). The existence of these challenges, therefore, may detrimentally affect farmer trust and interest in agrivoltaics and render the technology as an option only for large-scale developments that can afford to mitigate these challenges. As such, concerns over 'solar extractivism', wherein solar energy generation is prioritised over agricultural production in pursuit of a 'green [economic] agendas' have emerged (Hu, 2023: 1-2).

Due to the predominance of technical and biophysical agrivoltaics research, scholars argue that emerging agrivoltaics markets without proper regulation may prioritise development and profitability over community welfare (Hu, 2023). 'Solar extractivism' is characterised by developments driven by governments and corporations rather than in partnership with communities, and subsequent land-grabbing, corporate dominance over renewables, and social and environmental externalities (Hu, 2023: 1; Singh, 2022). Nevertheless, the presence of dispossession resulting from agrivoltaics development observed in research does not negate the value of the technology, rather it highlights the injustices that must be addressed in future research and policy. Further, it emphasises both the gap in literature evaluating the socio-economic implications of agrivoltaics implementation in practice as well as the importance of understanding these implications in different global and socio-cultural contexts.

Research beyond policy analysis has examined different agrivoltaics configurations and crop capabilities in predominantly feasibility and modelling studies. Research investigating grape farming in Maharashtra concluded that if similar systems were leveraged across India, they could generate '16,000 GWh [gigawatts per hour] of electricity', which is enough to power '15 million households' (Malu et al., 2017: 109). Trommsdorff et al. evaluated the socio-economic sustainability of agrivoltaics in Maharashtra as well and concluded that the proposed system was likely to 'almost double the average land use efficiency' through economic benefits from electricity generation and agricultural output (2022: 9). The authors further suggested that the presence of these benefits would not only reduce the risk of land-use conflict and but also alleviate poverty concerns through the addition of efficient water management strategies. While this research is significant, it was noted that further research on the socio-economic implications of agrivoltaics would be needed (Trommsdorff, Vorast, et al., 2022). Further, a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis was conducted to discern the biophysical and socio-economic implications of agrivoltaics (Mahto, et al., 2021). While this analysis found that the proposed environmental and socioeconomic benefits, such as increased crop yield and energy access leading to improved resource and financial security, have the potential to contribute to farmer well-being, it concluded that a lack of specific policy regulating the development practices of agrivoltaics might exacerbate existing inequalities and hardships. Mahto et al. (2021) argued that a specific focus on policy recommendations aimed at ensuring protections for rural Indian farmers who possess the most potential to benefit from agrivoltaics as well as the most risk would increase the potential for successful scale-out of agrivoltaics.

With any new technology, uncertainties that can impact the farming communities are expected. It is theorised in the literature that agrivoltaics may address daily uncertainties, such as climate irregularities leading to resource and financial insecurity and market unreliability (Gomez-Casanovas et al., 2023; Mahto et al., 2021b). Through the FEW nexus benefits provided by agrivoltaics, it is theorised that the technology has the potential to provide improved resource reliability that climate change has threatened (Barron-Gafford et al., 2019; Mahto et al., 2021). However, it has equally been observed that agrivoltaics systems may detrimentally impact crop yield, which may influence perceptions of risk among farmers who may be leveraging their livelihoods and savings (Mahto et al., 2021). One study concluded that sustainable and regenerative agricultural practices have the potential to improve small-scale farmer livelihoods and alleviate financial anxieties in India (Mariappan & Zhou, 2019). Feasibility studies in India have argued that agrivoltaics have the capacity to achieve these goals, even doubling a farmer's annual income, with just two hectares of land dedicated to agrivoltaics (Mehta & Winter, 2022; Trommsdorff, Vorast, et al., 2022). However, agrivoltaics will not contribute to these benefits if greater consideration for the potential innovative configurations that might render the technology more accessible to the average farmer. Current trends in agrivoltaics research and policy development indicate that the technology may prioritise large-scale 'green' development over community capacity building opportunities, contributing to concerns of 'solar extractivist' installations (Mehta & Winter, 2022; Pulipaka et al., 2024).

India has established itself as a leader in agrivoltaics research through its pilot programme, however, current trends of renewable energy development have influenced early decision-making on research foci and implementation policy. As multiple scholars have identified, there is limited research on the socio-economic implications of agrivoltaics development as well as in-depth understandings of lived experiences with the technology both in India and globally (Behuria, 2019; Galan, 2022; Trommsdorff, Vorast, et al., 2022). Further, if agrivoltaics are to be implemented in a sustainable manner, provide benefits across the FEW nexus, and address concerns from farmers over land use and accessibility, greater empirical attention to innovative configurations for the Indian context is required, and how to achieve agrivoltaics development without succumbing to exploitative implementation practices utilised in traditional solar installation.

Limited regulation and emphasis on market-driven approaches to agrivoltaics development may engender unjust agrivoltaics uptake in India. However, as will be discussed in this thesis, the innovative nature of small-scale and decentralised Indian farmers exemplifies alternative adaptions to agrivoltaics configurations that offer a wider understanding of the technology and its potential in different contexts.

Chapter 3: Examining Social Acceptance, Disruptive Innovation Potential, and Restorative Energy Justice of Agrivoltaics: An Analytical Framework

3.1. Introduction

The introductory chapter discussed agrivoltaics literature and provided an overview of the India's energy sector, including the nation's colonial history and its influence on the current renewable energy transition. This contextual background informs the analytical framework that I will apply to the examination of agrivoltaics in India to answer the questions posed by this research.

This analytical framework applies a novel form of social acceptance, disruptive innovation, and the concept of energy justice to examine the implications of agrivoltaics development in Northwestern India. Through analysing the acceptability of agrivoltaics prior to adoption and social acceptance perceptions following implementation, this research will evaluate how different stakeholders frame agrivoltaics, how these framings influence perceptions, and how these perceptions influence technological configurations among rural and decentralised farmers in India. Further, examining stakeholder perceptions, specifically those within the farming community, will assist in determining methods of adapting agrivoltaics to the Indian farming environment. This framework will contribute to the development of a realist theory-driven approach that explores the assumed and actual implications of innovative renewable energy interventions (Hewitt et al., 2013). This interpretation of the existing literature and theories will be combined with a social constructivist approach that assumes knowledge is created and reinforced through social interactions and structures, such as farmer or community-level interpretations and use of innovations, throughout analysis (Adams, 2006; Detel, 2015).

It is beyond the scope of this research to argue whether agrivoltaics is a 'good' fit for India, as to answer such a question would require significant time, extensive data collection, longitudinal research, and explicitly defining the meaning of 'good' in this context. Rather, my focus is to examine how agrivoltaics are presented by the literature and in documentation, framed by stakeholders, and how it has been taken up by Indian farmers to evaluate potential roadmaps for social acceptance and wider adoption.

This chapter will first introduce the social acceptance perspective, examining its roots in technological diffusion literature and its relationship with technological innovation systems research. This is a well-established field of research, and as such, will be evaluated only in the context of renewable energy, and where possible, solar energy. This section will conclude by discussing the agrivoltaics literature that employs a social acceptance lens and examining the limitations and gaps that call for greater attention in this growing body of work. Finally, this chapter will conclude by synthesising energy justice literature in the context of social acceptance and renewable energy development, before applying the framework to a specifical agrivoltaics context.

3.2. Social Acceptance

The concept of social acceptance is well established in the energy for development and society fields as an issue that shapes the 'successful implementation of new developments and technologies' (Upham et al., 2015:101). This statement indicates the significant role social acceptance plays in the success, both actual and perceived, of renewable energy development, including agrivoltaics. This section will introduce the literature on social acceptance before discussing the impact technological innovations may have on acceptability, as well as the role of accessibility and trust. To conclude, this section will review the small pool of existing literature applying a social acceptance lens to agrivoltaics to emphasise the specific gaps in agrivoltaics research.

Social acceptance is applied as a more nuanced alternative to understanding stakeholder and individual perceptions of technologies beyond the relatively limited scope of NIMBY-ism (Not-In-My-Backyard), which has been used as a frame to conceptualise public opposition to renewable energy systems (Batel, 2020). While NIMBY-ism is generally concerned with opposition, social acceptance as a concept refers to a range of perceptions. It is generally defined as a lens through which to evaluate adoption and retention rates of technologies (Alexandre et al., 2018a; Batel et al., 2013; Upham et al., 2015) but has grown along with the literature to include how stakeholders perceive a technology's impact within the socio-technical system and critique perspectives that overlook social dynamics (Batel, 2020; Fournis & Fortin, 2017). A socio-technical system (STS) approach emphasises the interdependency of technical and social systems, the ways in which each influence the other, and how each adapt and compromise to optimise a mutually beneficial system (Fox, 1995; Savaget et al., 2019). In this setting, systems thinking assists in understanding system change, including the ways in which aspects work together and contribute to both instability and resilience (Savaget et al., 2019). The inclusion of these definitions is useful to contextualise the literature reviewed in this framework, however a systems approach will not be undertaken in this research.

The earliest references to acceptance and adoption of technologies appear through the lens of the diffusion of innovation model (Upham et al., 2015). This linear model outlines five stages of technological diffusion. First is the knowledge stage, or when a stakeholder, or stakeholder group, is initially exposed to the innovation's existence and undertakes learning about it. Second is the persuasion stage, or when a stakeholder forms a 'favourable or unfavourable attitude' of the innovation based on the knowledge (Rogers, 1983: 164). The decision stage follows and refers to when the stakeholder 'engages in activities' that determine acceptance or rejection. Next is the implementation stage, or when the stakeholder puts the innovation to use. Finally, is the confirmation stage, or when the stakeholder finalises their opinion to continue using the innovation (Rogers, 1983: 164; Upham et al., 2015). According to this perspective, acceptance occurs during the persuasion and decision-making stages of a technology adoption process, as stakeholders begin to form opinions based on obtained knowledge and decide to adopt or reject the technology (Upham et al., 2015). However, acceptance is also considered to emerge during the knowledge stage when individuals and stakeholders are first exposed to the technology and recognises that opinions are formed throughout the learning process (Alexandre et al., 2018; Upham et al., 2015).

Further, in understanding social acceptance as a heuristic process, psychological and behavioural economics lenses can be applied to the persuasion and decision-making stages due to the perspectives developed in this field on causality and external influences on decision-making (Slovic et al., 2006; Upham et al., 2015). Sociological perspectives further scrutinise the decision-making process, emphasising that individuals are both connected to and a product of their social, physical, and technological environments (Upham et al., 2015; Glover 2019). In response to these approaches, Upham et.al. suggest an updated definition of social acceptance as 'a favourable or positive response (including attitude, intention, behaviour, and […] use) relating to a proposed or in situ technology or socio-technical system, by members of a given social unit' (2015: 103).

In parallel, social acceptance emerged as a concept to frame public perceptions and social resistance 'relative to market demands' (Fournis & Fortin, 2017: 2). While these conceptualisations remain prominent, scholars acknowledge that its applicability remains ambiguous, with authors using different terminology such as 'social' or 'societal acceptance', 'public acceptance', and 'social acceptability' interchangeably (Fournis & Fortin, 2017; Koelle et al., 2018). The practise of using such terms interchangeably is indicative of the spectrum of applications and the ambiguity of the concept itself but disregards the nuanced connotations each individual term possesses.

As noted above, multiple frameworks have been developed to conceptualise social acceptance, notably in the fields of behavioural economics (Frederiks et al., 2015), energy transitions (Cousse, 2021; Y. Kim et al., 2014), and social psychology (Alexandre et al., 2018). As a concept, it is utilised to gauge and understand stakeholder response to energy infrastructure (Batel, 2020), which can be visualised as three different levels: the micro, or the individual, including households and community organisations; the meso-level, or the community, town, or 'geographically defined' level; and the macro, or the policy or country level, and includes acceptability in a more general sense (Upham et.al., 2015: 104; Torma et.al. 2024).

A complimentary understanding of this level approach considers a 'triangle of social acceptance' (Fournis & Fortin, 2017: 3). This includes socio-political acceptance, which relates to the macro-level, more overarching public opinions of acceptance. Secondly, community acceptance relates to the individual or local scale micro-level but distinguishes itself by centring justice concerns in its conceptualisation. Thirdly, market acceptance can refer to the regional, meso-level as markets of scale can integrate consumers, investors, and businesses, however this term differentiates itself by also considering the process of innovation adoption (Fournis & Fortin, 2017). The multiple conceptualisations of social acceptance further emphasise the importance of context when evaluating acceptability.

For instance, political acceptance (i.e. a specified category within the macro level) necessitates policy support by different levels of government and political parties but also applies to stakeholder acceptance that have an interest in the outcome of a technology's introduction despite lacking political connections (Motosu & Maruyama, 2016).

The political and stakeholder contexts of acceptance are focused mainly on the technology itself and its collective impacts. Consequently, acceptance at these levels legitimise their eventual decisions. Scholars have found that individuals and community groups are generally more accepting of technology once it has been approved at a more official level (Guo & Ren, 2017), however, this is not always the case. Settings with higher levels of corruption, distrust of the government, or even negative emotional responses to a specific technology are all potential reasons why social acceptance diminishes, as a direct result of the dissolution of trust in elites (Li et al., 2021).

As such, individual acceptance is more internal, driven by behavioural intentions and actual behaviours, as well as attitudes and personal feelings about an energy technology and its potential socioeconomic implications (Guo & Ren, 2017; Upham et al., 2015). Individual opinions can be formed through the dissemination of information about a new technology (for example, during the knowledge phase, or through a more heuristic process), however it has been found that people are more susceptible to decision-making based on the conscious or subconscious perceived risks and benefits of a technology (Lienert et.al., 2015). In a process known as affect heuristic, individuals tend to view a technology more highly if they judge the benefits to be greater than the risks based on their perceptions of previous incidents or installations. Whereas if they judge the risks to be too high—for example, the wariness of nuclear energy following the 2011 Fukushima meltdown disaster (Guo and Ren 2017)—they trend towards an unfavourable opinion of the technology (Lienert et al., 2015; Slovic et al., 2004, 2006). While both political and stakeholder acceptance can be driven by behaviour and personal benefit in ways that can perpetuate marginalisation of other groups, these contexts generally deal with the collective impact and are thus dependent on more distributed benefits and risks rather than personal impact. However, as energy systems increasingly become more decentralised, power relations between traditional and non-traditional energy actors and their consequent influences on acceptability are beginning to shift (Brisbois, 2023). The overlap between levels of acceptance further exemplifies the fact that social acceptance is not as linear a process as once theorised.

Just as there are multiple frameworks used in research that seeks to understand social acceptance, there are multiple approaches that have been adopted for evaluating and measuring such acceptance. These approaches range from ergonomical tool-centred approaches focused on usability and accessibility criteria to social psychology lenses that evaluate the 'social determinants of tool use' based on notions of intention, performance, subjective social norms, and user agency to in-depth productivity models and evaluations of user satisfaction (Alexandre et al., 2018: 166). It is evident that evaluating social acceptance involves multidisciplinary and contradictory pathways of assessment, and thus no specific criteria for measuring or method of ensuring acceptance. Rather, context and subjective priorities of evaluators determine how social acceptability and acceptance is determined.

Despite this range, stakeholders and researchers primarily utilise acceptance as 'an indicator of success, or successful integration of a technology, and treat it as separate from 'other dimensions of social reactions' (Batel et al., 2013; Upham et al., 2015: 105). Consequently, scholars argue that the term itself (acceptance) is problematic due to these attempts at narrowing down these multitudinous conceptualisations to a single word that connotes only a dichotomous choice of either acceptance or rejection, which oversimplifies the complex interactions within the sociotechnical system (Ricci et al., 2008; Upham et al., 2015). In fact, consistently viewing acceptance as a linear process sustains the 'normative top-down perspectives on peoples' relations with energy infrastructures' and disregards any other type of responses to technology, including but not limited to support, uncertainty, resistance, and even apathy (Batel, 2020; Batel et al., 2013). This reducing of technological social acceptance to an either/or decision minimises the range of valuable perceptions stakeholders might have and thus limits the potential for a more robust understanding of the technology itself, from implementation to its long-term implications.

Considering the multiple conceptualisations of social acceptance in the literature, scholars clarify the difference between acceptance and acceptability, however, recognising that often the two terms are used interchangeably in the literature (Alexandre et al., 2018; Fournis & Fortin, 2017). Acceptance is a 'posteriori pragmatic evaluation,' or requires previous experience using the technology before deciding to accept or reject it (Alexandre et al., 2018: 165). In contrast, acceptability involves the 'explicit willingness' to use a technology, or the positive perception of the technology prior to using it (Alexandre et.al., 2018: 165-166). Acceptability is understood as a broader concept than acceptance as it is a symbolic, contested, and dynamic process that is informed by 'collective norms […], diverse evaluation processes […], and […] by an acknowledgment of the legitimacy of behaviours (Fournis & Fortin, 2017: 5). Inherently, acceptability refers to the pre-existing societal norms and policy landscape that influence the conditions upon which approval would be contingent. Scholars argue that this understanding of acceptability as a socio-technical contract is therefore problematic due to the political influences (Fournis & Fortin, 2017).

While it is evident that acceptability can influence a technology's eventual social acceptance, these two concepts are not mutually exclusive. Both public opinion and political influences have the potential to shift, rendering a previously accepted technology unacceptable or preventing acceptance in the first instance. Despite the nuance inherent in the terminologies' connotations, 'social acceptance' is continually utilised as an overarching term to refer to both acceptability and acceptance. Nevertheless, the distinction between the two is crucial in the following discussion of renewable energy innovation and implementation.

Generally, public support of renewable energy is understood as more favourable through a sense of genuine support, moral obligation, or conditional approval (Liebe & Dobers, 2018). For example, while wind turbine developments are considered a provider of societal benefits, these perceived benefits nevertheless conflict with costs focused on localised areas. These costs include landscape disruption and degradation, noise, shadow flickering, and detrimental impacts to wildlife, often leading to local opposition and ultimately, rejection (García et al., 2016; Hai, 2019; Haikola et al., 2019). Despite the understood collective benefits presented by technologies like wind turbines, personal opinions have been observed to shift when directly impacted by their development. Social acceptance, therefore, is inherently related to an 'evolving social contract' with a renewable energy technology wherein detrimental implications of development impact shifting opinions (Fournis & Fortin, 2017: 4). While there is certainly overlap between social acceptance and its precursor NIMBYism, what distinguishes the two is that social acceptance is not wholly dependent on 'backyard' impacts. Rather, social acceptance depends on other factors, such as cost, trust, and collective benefits, in addition to location, and leaves space for a spectrum of emotional responses beyond acceptance or rejection.

3.2.1. Reluctant and Conditional Acceptance

Accordingly, a subset of social acceptance literature specifically looks at the nuance within decision-making and is conceptualised as *reluctant* acceptance (Haikola et al., 2019; Kim et al., 2014; Venables et al., 2009). While this concept is primarily applied to discussions surrounding the social acceptability of nuclear energy (Guo & Ren, 2017; Kim et al., 2014; Mah et al., 2014), it has a broader applicability to other contexts and energy technologies. The notion of reluctant acceptance can be visualised as a way of capturing the grey areas between the binary of acceptance and rejection. This can include the uncertainty and apathy as Batel (2020) notes; however, it may also encapsulate more nuanced behavioural, emotional, and social psychological perspectives (Alexandre et al., 2018b; Goyal & Howlett, 2020). For instance, subjective social norms (e.g. societal peer pressure toward climate protection) may influence individuals to support the installation of wind turbines or solar panels only because they are convinced others are also doing so or may only support the projects when they are not within their immediate vicinity (Liebe & Dobers, 2018). Another example of nuances within reluctant acceptance involves communities that have no other choice but to accept the introduction of a new technology. This includes individuals who are sceptical of nuclear power due to risk of meltdowns and nuclear waste, are doubtful it is the 'right' direction for climate protection or must reluctantly accept their presence after their local authority opts in to its energy supply (Pidgeon & Demski, 2012; Venables et al., 2009). This reluctance can also be applied to renewable energy systems whose development correspondingly involves ecosystem and sociocultural impacts. In these cases, the reluctant individuals are not tasked with making the decision themselves but nevertheless experience emotional responses to the introduction of the technology or grudgingly accept a technology's presence despite preferring alternative configurations or a completely different technology.

The related notion of *conditional* acceptance refers to social acceptance that is preconditioned on specific alterations or adaptations to the proposed technology (Liebe & Dobers, 2018). An example of this could include a community approving a commercial solar development only if it is discretely built with the intention of blending into the landscape, or only on private land (Pascaris et al., 2022; Torma & Aschemann-Witzel, 2023). What ultimately distinguishes conditional from reluctant acceptance is where in the timeline of energy system implementation acceptance is given, if at all. Conditional acceptance refers to the conditions upon which a technology's adoption is dependent, whereas reluctant acceptance is understood as a spectrum of emotional responses throughout the implementation process, including post-adoption.

Regarding nuance within acceptance processes, it is important to acknowledge not only vocalised responses but to also consider the potential meanings behind silence from potential stakeholders and adopters. For instance, in Japan, Motosu and Maruyama (2016: 369) found that developers interpreted individuals' silence over wind developments as 'passive approval' during a mandated environmental impact assessment process without any intention to follow-up on potential implications of such a development. Instead of simply reading this silence as approval, researchers have emphasised the potential meanings of silence (Motosu & Maruyama, 2016). A lack of response from potential stakeholders or users can indicate a lack of access to both knowledge and participatory processes, as well as language, cultural, and structural barriers that prevent an individual or group from commenting. Thus, opportunities for participation may be proposed as a condition for approving such projects. Community involvement throughout the early stages and decision-making processes can increase likelihood of 'active support' and acceptance as a result (Motosu & Maruyama, 2016: 370). Correspondingly, silence or limited responses following the installation of an energy system also does not constitute blanket acceptance. Rather it can indicate a grudging acceptance (Keeley, et a., 2022; Motosu & Maruyama, 2016) after residents experience the reality of the system but have no recourse to protest post-installation especially as energy systems have lengthy land lease periods, and thus presence on the landscape.

Reluctant acceptance does not exist solely as a direct result of lived experiences; however, it is inferred that wider swaths of emotional responses will result following real-life experience with a technology, rather than basing perceptions off perceived benefits and risks (Alexandre, et al., 2018). It is in this way that reluctant acceptance is conceptualised to include the nuance in individual and community perceptions of a technology based on lived experience, conceptualised as a spectrum of acceptance.

Interestingly, some researchers in the community energy field have observed that communities are more accepting of renewable energy (wind turbines in this case) if they have a significant role in the decision-making process and even ownership models (Berka & Creamer, 2018; Ketzer, Weinberger, et al., 2020). Scholars recognised the popularity of community-owned wind farms in Japan that centre community benefits rather than solely economic benefits for the developers at the expense of the local residents (Toke et al., 2008 cited in Motosu & Maruyama 2016). Cases such as this are indicative of the fact that understanding social acceptance requires more nuance, including the consideration for the possible meanings present within silences, and that attention given to community participation engenders acceptance and positive perceptions of a technology.

While these cases are focused on wind energy, they highlight the significance of considering developmental implications on communities during energy transitions. Renewable energy transition has in some cases been planned and designed to be more community focused, such as through distributed and off-grid systems, however, with a growing push among policymakers in many countries toward a net-zero transition, these installations have increased in scale and in some cases mirror dispossessive and unjust aspects of conventional, centralised and fossil fuel based systems (Singh, 2023; Dunlap, 2017). Such energy systems, such as natural gas pipelines and oil rigs and refineries, increase the likelihood of negative perceptions and rejection of the renewable technologies (Sareen & Kale, 2018). The specific ways in which renewable energy systems can cause community harm draw attention to the relationship between community participation and social acceptance. Community participation within the decision-making process can support just energy systems, often broadening social acceptance. However, the implementation, combined with a history, of large-scale renewable energy systems that dispossess communities of land and livelihoods are understood to engender negative perceptions of the technologies and diminishing social acceptance levels (Lakhanpal & Chhatre, 2019; Sareen & Kale, 2018; Singh, 2024). However, this perspective is underexamined in the research, particularly in reference to marginalised, indigenous, or other vulnerable groups in Global South contexts, and requires further analysis.

3.2.2. Limitations of Social Acceptance Literature

In recognition of nuanced perspectives on social acceptance, critiques within the field have grown. Batel (2020) developed a theoretical framework critiquing social acceptance perspectives in renewable energy development contexts specifically. They visualised three thematic pathways: normative, criticism, and critique. The first wave (normative) acknowledges that renewable energy technologies produce socioeconomic implications and argue that academics must 'come up with possible responses and ways to reduce opposition' (Batel, 2020: 2). This first wave represents the current 'normal' approaches to technology implementation, which views the process as linear, accepts no vocal opposition to equate passive acceptance, and if there is opposition, decisions for how to overcome it remain within the closed circle of experts, developers, and other elites. The second wave (criticism) focuses on examining opposition beyond local stakeholders and communities by considering other relevant actors, such as developers and policymakers. This wave assisted in initiating some communication between actors in attempts to limit detrimental socioeconomic impacts of renewable energy deployment (Batel, 2020: 2). By critiquing the existing normative systems of energy development that disregard community perspectives, this wave of research recognises the importance of introducing more participatory opportunities within developmental processes (Ibid). Finally, the third wave (critique) builds upon the previous pathways by 'interrogating and criticising' them and highlighting the opportunities for discrimination, injustice, and inequalities within renewable energy development processes so that they can be addressed (Batel, 2020: 2).

By doing so, these critiques recognise the intricacies of the sociocultural and 'socio-psychological' factors both internal and external that influence community perceptions of renewable energy (Batel, 2020: 2). These critiques have spawned an increase in research on the dispossessive potential of renewable energy stemming from neoliberal capitalist systems, a fact that is often overlooked in favour of promoting such developments (Batel & Devine-Wright, 2017; van Veelen & Haggett, 2017; Clark & Gunaratnam, 2022; Singh, 2022). They have also fostered perspectives on the social potential of community involvement in more decentralised and innovatively designed energy systems as an anathema (Goedkoop & Devine-Wright, 2016). While scholarship examining peoples' responses to dispossession caused by large-scale renewable energy has grown, including how neocolonial practices legitimise land appropriation by state actors and elites (Baka, 2017; Singh, 2022), more attention is needed on the ways that marginalised community perspectives on renewable energy technologies influence acceptability and acceptance.

Notably, existing studies applying the social acceptance lens to solar energy remains limited, especially in relation to other energy technologies, and thus, emotional reactions to solar siting remain under-researched (Cousse, 2021; Hai, 2019; Torma & Aschemann-Witzel, 2023). While the acceptability of wind and solar energy overlaps in certain regards, including increasing cost-effectiveness, there is a stark difference between the two energy systems' sociotechnical configurations. Wind turbines can be community owned and small-scale, however they are more frequently installed in large-scale developments by large firms and investors to maximise energy production, cost efficiency, and dispersed social benefits (Garcia et al., 2016; Motosu & Maruyama, 2016). Solar energy can be installed in utility scale developments, however in comparison with wind there is greater flexibility in configuration type, including community-owned systems, rooftop solar, stand-alone systems and micro-grids (Jing et al., 2022; Gamarra et al., 2019). Despite this flexibility, utility-scale solar is still considered desirable to developers due to its cost and energy efficiency (Baker & Sovacool, 2017).

The affordability of renewable energy technologies like wind and solar are correlated with scale, however such large developments tend to reduce overall social acceptance due to land competition fears (Torma & Aschemann-Witzel, 2023). In fact, larger proposed projects have been found to be less favourably received by communities than smaller sites (Cousse, 2021). It is understood that the renewable energy transition involves the 'extension of the energy system' into 'formerly untouched' places as identified by often neoliberal or (neo-) colonialist elites, and such 'interference with previously "unaffected"' landscapes influence local acceptance of the technology (Cousse, 2021: 2; Baka, 2017). Whereas energy systems and other infrastructure have traditionally been invisible, only made visible by their 'absence through power outage or unaffordability' (Dunphy & Lennon, 2022: 432), it is the increased visibility of renewable energy systems, including solar, that affect local acceptance (Ketzer et al., 2020). There exist significant opportunities to examine the social acceptability of solar energy, including how the scale of solar developments or new configurations and innovations of solar influence processes of social acceptance. Further, there is room to analyse the relationship between the dispossessive potential of large-scale installations and solar acceptance, especially in the Global South. While this broad potential is mostly beyond the scope of this research, its inclusion in this analytical framework is crucial to contextualise the multifaceted nature of social acceptance literature pertaining to solar energy specifically.

Social acceptance is inherently linked with technological implementation and adoption. Consequently, technological innovation influences changes in social acceptance and perceived social acceptability in turn influences innovation design and framings. The usage and acceptance of technologies, including renewable energy systems, are recognised as dynamic and even subject to change (Upham et.al., 2015). Thus, as technological innovations continue to be introduced, so too must understandings of social acceptance. The following section will introduce the concept of technological innovation and its relationship to renewable energy transitions and their acceptability.

3.3. Innovation Systems

The concept of innovation systems was first developed as a reaction to the 'perceived inadequacies of neoclassical economics and the spread of neoliberalism' and established as a process of addressing and 'reconfiguring' perceived systemic weaknesses (Jacobsson & Bergek, 2011: 42, 48). In other words, innovation systems frameworks are utilised to evaluate historical and present socioeconomic and political systems that influence technological diffusion and systemic changes required to foster innovation. There are more specific diversions of this concept, including but not limited to: national innovation systems, regional innovation systems, technological innovation systems, and agricultural innovation systems. Two of these will be explored in the following section, specifically technological innovation systems and agricultural innovation systems, to understand how various systemic features enable or prohibit participation, trust, and acceptance of innovations such as agrivoltaics. However, while these different conceptualisations are specified above, they are recognised to be interrelated, hence their inclusion here. For example, any change within a technological innovation system, such as the introduction of new technology, influences and is influenced by the national and regional innovation systems that consider institutional or political changes for such an innovation to occur. Nevertheless, a technological innovation system approach is often utilised to analyse the emergence of new energy systems (Jacobsson & Bergek, 2004, 2011).

Innovations occur following the recognition of weaknesses within a complex system and encourage a reconfiguration process of the system's components, such as the formation or improvement of new social and knowledge-sharing networks that enable technological uptake (Douthwaite, 2006; Herman, 2023). However, innovation does not occur in a linear fashion. In fact, institutional weaknesses can involve government or research bodies channelling all effort into one feature of innovation, such as 'knowledge development' rather than dissemination or allowing for engagement of other stakeholders within the knowledge development phase (similar to the theory of technological diffusion, introduced in the previous section) (Jacobsson & Bergek, 2011: 48). This prevents the creation of a more robust understanding of an innovation, including novel uses and potential implications that only may be introduced through more participatory and co-development strategies. In addition, network weaknesses, such as disconnects between stakeholder groups, can also block knowledge development and diffusion due to the lack of 'outsider', or non-elite participation (Jacobssen & Bergek, 2011: 48). Such weaknesses are not always apparent, as 'incumbent', or mainstream, systems and technologies are viewed as established, are continually justified through 'sunk-cost' arguments (Kivimaa & Kern, 2016: 210), and subsequent lock-in. However, a lack of vibrant and active experimentation and collaboration only allows for technological innovation systems to stagnate (Goyal & Howlett, 2020; Jacobsson & Bergek, 2011).

Such experimentation enables 'bi-directional learning' and 'twin-track development' wherein it is understood that potential stakeholders do not build knowledge equally, at the same speed, or takeaway the same lessons (Goyal & Howett, 2020: 316). Rather, this process produces 'congruential rather than consensual learning' (Goyal & Howlett, 2020: 316, citing Seyfang et.al., 2014; Brown et.al., 2003). In essence, different stakeholders coming from multiple perspectives (e.g. market, policy, social, environmental, technological) across multiple levels (e.g. national, regional, and local) understand an innovation and its potential benefits and costs in unique ways, ultimately contributing to a more robust knowledge base.

Barriers to experimentation can result from a lack of relevant actors within the system to perform such experiments, whether in academic, market, or community settings, as well as profit-seeking, risk-averse parties hesitant about investing in long-term and high-risk (innovative) projects, specifically those that require significant commitments (Jacobsson & Bergek, 2011), such as large-scale renewable energy installations. However, without providing opportunities for experimentation, there is thus no market interest in any deviation from the incumbent systems, or innovation (Jacobssen & Bergek, 2011).

Interest in an innovation process, such as through knowledge development spearheaded by institutional support, generates a sense of legitimacy for the innovation itself and consequently encourages market formation, which in turn enables experimentation with the innovation (Guo & Ren, 2017). Legitimacy-building is a process that takes time and is often met with opposition from groups with vested interest in incumbent technologies, however with 'conscious actions by organisations and individuals' this process can help innovations overcome any '"liability of newness"' (Jacobsson & Bergek, 2011: 51).This provision of legitimacy is further understood as enabling social acceptance as individuals and stakeholder groups perceive the innovation in question as an opportunity rather than a risk, which is ultimately dependent on trust in institutions (Alexandre et al., 2018).). Such acceptance of an innovation is required for many other components within the system to 'work', including for the appropriate 'resources to be mobilised' and for 'actors to acquire political strength' to foster experimentation (Jacobsson & Bergek, 2011: 51).

Agricultural innovation is also viewed as a 'co-evolutionary process', or one that combines technological, social, economic, and institutional change through the exchange of knowledge and the balance of adopting new technologies, introducing new practices, and restructuring markets, labour, land tenure, and resource distribution (Klerkx et al., 2012: 458). Two pathways to conceptualise agricultural innovation emerged concurrently: Agricultural Knowledge and Innovation Systems (AKIS) and Agricultural Innovation Systems (AIS). AKIS emerged as a critique of the earlier linear models of innovation that mirror the diffusion of technology models and as a method of viewing the interlinkages between agricultural systems and other stakeholders within that system. However, this concept assumes that agricultural systems 'exist independently from the observer' and can be 'analysed, understood, and engineered towards an unambiguous goal' (Klerx et al., 2012: 462-3). In other words, AKIS views agricultural systems as independent systems that are unaffected by outside influence, when institutional barriers, markets, and policy enabling environments impact the efficacy of the system (Hall et al., 2006). Further, a researcher analysing the system cannot be as impartial or invisible as preferred, as their ideas and simple presence can influence actions taken or words spoken by those who exist within the system. While the AKIS framework recognises the importance of knowledge sharing between farmers and researchers, it is assumed that new technologies will be transferred from researchers to farmers in a one-way rather than bi-directional process (Hall et al., 2006; Klerkx et al., 2012).

In contrast, the Agricultural Innovation Systems (AIS) perspective includes the 'complex interactions between a multitude of players and sub-systems that [characterise] innovation' (Klerkx et al., 2012: 464). Essentially, AIS recognises the interplay that exists within and between systems and attempts to provide a comprehensive view of all actors that 'co-determine' innovation processes (Douthwaite et al., 2001: 178). However, despite this holistic approach, scholars recognise that this lens has limited scope for the conflicting goals, interests, and perspectives of different actors within the system, which can lead to conflict and miscommunication (Douthwaite et al., 2001; Klerkx et al., 2012). Ultimately, AIS focuses on 'multi-actor interactions and structures' that may serve to enable innovation, while also understanding that effective innovation processes require coordination between relevant stakeholders and sub-systems (Klerkx et al 2012: 464). However, despite the acknowledgement of this complexity, this lens does not consider the different framings different stakeholder groups can apply to a technological innovation, which in turn would influence perceptions and acceptability.

Each of these frameworks assume communication and interactions between stakeholder groups but neglect to evaluate the implications of transferring knowledge. Glover et.al. (2019) argues that technologies are 'translated' rather than directly transferred, acknowledging that different actors and stakeholders have different frames and knowledge bases that adapt the technology and render it more 'meaningful' for that specific context (Glover et al., 2019: 171). This perspective emphasises that technologies designed for a specific purpose or context cannot be directly transferred to a new setting without adaptation. Yet, within agricultural systems, scholars critique the fact that technological innovation adoption rates are dependent on ensuring the technology is 'right', while stimulating institutional structures to encourage uptake, including through 'influencing the dispositions of farmers through advertising, training, and support' (Glover et al., 2019: 176, citing Orr 2018). Influential stakeholders, such as corporations, governments, and elites, are generally perceived to hold more power over 'ordinary citizens, […] marginalised people, and dispossessed minorities' and contend they alone can make the 'right' call (Glover et al., 2019: 171). The decisions made regarding technological change by elites often provide a sense of legitimacy and maintain the incumbent system. However, this approach can also perpetuate the marginalisation of users who are not only seen as 'passive adopters' but also ‘victims’ if the innovation is not designed to be adapted or locally ‘re-invented’ (Glover et al., 2019: 171).

Similar to the AIS framework, this conceptualisation views technological change as a process that depends on academic and other expert understandings of the technology. Further, it also does not consider the potentially conflicting framings of an innovation and instead encourages the development of specific frames of the technology that in turn influence the farming community. Glover et.al., (2019) critiques this perspective of agricultural innovation as they do not centre the farmers’ agency or ingenuity within this process.

Despite the focus on a more iterative approach within AIS that attempts to prioritise co-development of innovation, this co-development, or experimentation through knowledge exchange, is not common in practice. This perspective makes assumptions about the capacities of farmers without understanding that the farming community possesses crucial knowledge that the other stakeholder groups that are attempting to encourage innovation adoption have not considered. Through the discussion of AIS, the combination of knowledge exchange and providing opportunities for experimentation outside the academic and expert spheres encourages a more robust understanding of not only technology but the socioeconomic, cultural, and environmental implications of its implementation. Innovation and experimentation include investigating how the technology can be marketed and implemented, but also how it can be adapted to new and previously un-considered contexts. Each of these factors influence the acceptability and ultimate acceptance of a technology and can result in what is called disruptive innovation. This process is explored in the next section.

3.4. Disruptive Innovation

Disruptive innovation involves a novel technology or technological adaptation that challenges the incumbent technology but also represents an evolving process. Disruptive technology innovation does not point only to the outcome, e.g. the innovation itself, but also to the iterative and ‘bi-directional’ processes that result in such innovation and adaptation (Goyal & Howlett, 2020; Si & Chen, 2020). Originally proposed by Christensen (1997), disruptive innovation is understood as a technology, business, or product that ‘significantly affects’ the ways in which a system functions and can result in conflicts as the introduction of a novel way of doing things challenges the ‘institution of existing ones’ (Liu et al., 2020: 314; Christensen et al., 2018). Liu et.al. (2020) simplify this definition to consider disruptive innovation as a type of technology designed to replace the existing mainstream technology in ‘unexpected ways’ (315). While the nature of these ‘unexpected ways’ is left ambiguous in the authors’ text, it can be understood that the opportunities for experimentation, which are crucial for innovation processes, are just as relevant here and open to interpretation and the ingenuity of specific participants. Nevertheless, Liu et.al. (2020) write that disruptive innovation has three key characteristics that should be followed: low-cost, highly convenient, and ability to 'comprehensively reduce' the total cost for the target market (316).

What separates disruptive innovation from the more critical conceptualisations of innovation systems is the opportunities present for 'outsiders' to participate and challenge the mainstream (Kivimaa & Kern, 2016: 210). While studies of innovation focus on facilitating technological innovation systems which might overturn 'incumbent regimes' (i.e. the mainstream processes), Kivimaa & Kern (2016: 205) turn their attention to transitions that weaken the 'reproduction of core regime elements [by] upscaling…niche innovations' through the combination of both disruptive innovation and 'disruptive policy mixes' that enable systemic change. The authors clarify that while the prospect of challenging the mainstream may be a common feature of technological innovation systems that implicitly act as a tool for identifying weaknesses within an existing regime and offering alternatives, such as through experimentation, these processes do not always lead to the 'destruction in the dominant regime' (Kivimaa & Kern, 2016: 210-11). To achieve this destruction, the development of 'niche innovations and new technological innovation systems with attention to regime destabilisation' and supportive and innovative policy mixes need to be undertaken and applied in 'mutually reinforcing' ways (Kivimaa & Kern, 2016: 211). These scholars call this process 'creative destruction', and through disruptive technological innovation, it encourages 'processes by which resources, skills, and knowledge held by incumbents become obsolete' and replaced by new knowledge (210). Such radical processes are already occurring and some becoming widely socially accepted. For instance, the community-owned wind turbine systems in Japan that prioritised socioeconomic benefits for the community over the developers and policymaker interests have improved acceptability of wind turbines in this context, encouraged the likelihood of future participation, and generated positive perceptions of the technology as community agency over the system has improved (Motosu & Maruyama, 2016). Another example of disruptive innovation includes the Indonesian Go-Jek application that originated as a kind of Uber for motorbikes but quickly transformed into a one-app stop for deliveries, social media, and even banking (Suseno, 2018). Through similar community adaptations to existing technology, it can be assumed that community-owned and decentralised renewable energy systems challenge the incumbent energy regime by requiring adaptations in policy and technological innovation.

The inclusion of 'outsiders' within innovation systems can lead to more disruptive processes as they are not 'tied to perpetuating the existing way of doing things' in the same way as incumbents can be (Kivimaa & Kern, 2016: 213). As mentioned, these processes of perpetuation tend to result from close relationships between incumbent and government actors that feel locked-in to the existing system (Kivimaa & Kern, 2016, citing Unruh, 2000), however it is the 'outsiders' that are more likely to develop radical innovations that are more accessible and acceptable (Kivimaa & Kern, 2016). In fact, it has been found that newer and often, smaller, companies with fewer resources are better placed to challenge established businesses (Christensen et al., 2018; Suseno, 2018). This exemplifies the need for experimentation within systems and allowing for participatory and collaborative opportunities for groups that normally would not be included in the mainstream. For example, including farmers in discussions of solar energy development has not always been considered necessary by other stakeholder groups, such as policy and market actors, but have been recognised as crucial for agrivoltaics research (Ketzer, Weinberger, et al., 2020; Torma & Aschemann-Witzel, 2023).

Further, evidence has grown in recent years that shows how disruptive and radical innovation processes improve social wellbeing, generate considerable revenue, facilitate 'social connectedness', 'enable trust, […] create a shared understanding in society', and produce products that improve standards of living (Si & Chen, 2020; Suseno, 2018: 189). As such, scholars stipulate that disruptive innovation processes are best suited for developing countries and are even considered an 'essential growth mechanism' for emerging economies that cannot implement incumbent mechanisms for any number of reasons, including but not limited to affordability, cultural acceptability, or limited place-based knowledge (Liu et al., 2020: 317; Si & Chen, 2020; Suseno, 2018).

The Indian concept of *jugaad* refers to versatility, flexibility, and the sensibility and ability for and enabling of improvisation (Kumar 2024). It encapsulates a non-Western, postcolonial (Kumar 2024), approach to disruptive innovation wherein 'outsider' or non-elite perspectives influence an innovation's design and ultimate use, effectively challenging the established systems. A Punjabi word, *jugaad* is widely used across northern India is a 'complex and context-specific sociological phenomenon' that often exists in 'grey' and informal spaces and combines innovation, entrepreneurship, social disruption, and/or corruption (Narayanan, 2019: 1517). Thus, *jugaad* is not limited to material infrastructure, but also includes *jugaadu* people, or improvisors, who enact (or embody) flexibility to draw on sociocultural, political, and material resources to 'twist unfavourable alignments into somewhat favourable ones' (Kumar 2024: 4).

While *jugaad* can refer to more dynamic, and thus more useful, innovative products, *jugaad* can still exist within incumbent systems, by creating an innovative product that exists within the mainstream and thus remains static in its usefulness (Kumar 2024). *Jugaad* can be a source of innovation, wherein frugality both in design and diffusion is considered, such as the versatile solar lamps used in rural India, and ultimately leading to conceptualising *jugaad* as 'frugal innovation' (Prabhu & Jain 2015: 845), or *jugaad* innovation (Radjou et.al., 2012). It can also be used to legitimise corrupt practices that circumvent the establishment, in the same way disruptive innovation subverts the incumbent processes (Kumar 2024). In the first instance, innovative products can be designed with *jugaad* in mind, however these for-profit companies still design these products within 'carefully managed parameters' to sell 'better' or effective products rather than allowing for 'flexibility and adaptability [as] determined by the end-user (Kumar 2024: 8). This 'neoliberal co-optation' of *jugaad* (Kumar 2024: 12) ultimately produces innovations that exist within the boundaries of the incumbent systems. It still involves a person or group's sensibility for flexibility and experimentation, and the creation of 'ingenious, critical alternative systems' through resourceful behaviours, collaboration, and innovations (Naranayan 2019: 1517). However, for this static idea of *jugaad*, the process has an end point, and the innovation is 'sold as a settled product' (Kumar 2024: 14). In practice, *jugaad* is an ongoing process that can be adapted to specific uses or contexts, and thus 'consistently threatens any idea or ideal of a settled product' (Ibid). *Jugaad* remains a 'key resource for progress in obstructionist environments', including inefficient and corrupt bureaucracies, as well as static, incumbent systems (Naranayan 2019: 1517-8). Essentially, the inclusion of 'outsider' perspectives with their unique and contextual sociological and material resources may generate *jugaad* to disrupt the established processes and 'make things happen' (Narananyan 2019: 1517) in 'unexpected ways' (Liu et.al., 2020: 315).

Disruptive innovation is a process that requires the radical participation of 'outsiders' within technological innovation systems that create new or adapt existing technology in ways unpredicted by institutional elites (e.g. academics, developers, policymakers) that then challenges, and even overthrows, the status quo. Such processes require an understanding of the mutually beneficial nature of innovations, opportunities for experimentation and risk, and trust. Disruptive innovations may emerge with lower levels of acceptability in relation to their ultimate acceptance following user testimonials. Such processes may require a certain level of word-of-mouth support within and between groups to encourage acceptance over time as pre-use acceptability may be low due to an innovation's nascency and relative unknown. However, as Suseno (2018) points out, trust 'underpins social capital through norms of reciprocity' that in turn generates a more efficient and cooperative society (183). When trust is present within innovation systems and thus allowing space for experimentation and risk as well as innovation, then it is understood that communities, groups, and individuals are more accepting of systemic change. However, an enabling environment supported by community groups, policymakers, and other stakeholder groups based on mutual trust and understanding for radical systemic transformation is not one that is easily created, as exemplified by instances with limited opportunities for 'bi-directional' learning (Goyal & Howlett, 2020: 216). Nevertheless, the review of disruptive innovation processes will assist in the ultimate conceptual understanding of the many facets of novel energy technological acceptance and implementation, and how these processes influence stakeholder perceptions.

At time of writing, this concept has not yet been applied to agrivoltaics despite its potential to disrupt the incumbent implementation practices of solar energy by holistically integrating food and water security into a renewable energy installation at different scales. Nevertheless, this is an interesting avenue for exploration to consider the disruptive potential of such innovations and diverse configurations and degrees of community and farmer participation that may coincide.

3.5. Examining the Relationship between Acceptance and Innovation

As noted above, technological innovation relies on the perceived legitimacy of the innovation and an individual's or group's trust in the institutions that are promoting and disseminating that innovation. Opportunities for bi-directional learning and knowledge exchange increase the accessibility of innovations and ensure that innovation is both flexible and adaptable to planned and unpredicted contexts (Alexandre et.al., 2018). Uncertainties in innovation discussions indicate a lack of access of information for potential users to refer to, resulting in unwillingness, reluctance, and rejection outcomes (Hai, 2019). After all, the accessibility of a technology is a 'precondition of usability', or the ability for a technology to be used, and thus influences perceptions and ultimately, acceptance (Alexandre et.al., 2018).

Finally, as established, trust is an important factor in the decision-making and social acceptance processes (Alexandre et.al., 2018; Cousse, 2021). Researchers have emphasised that trust in institutions and elites, including academia, plays an important role in the perception of social risk and acceptance. While not explicitly stated in the literature, trust is inferred to be a precondition of acceptance and one that influences the evolving perceptions of an innovation. As will be further elaborated on in the following section, the existence—or absence—of trust is inherently instrumental to the central pillars of energy justice.

The accessibility, flexibility, and adaptability of an innovation represent context specific conditions upon which social acceptance and eventual uptake are dependent. If there is limited trust in the institutions promoting the innovation, it is unlikely that individuals would have enough trust in their ability to understand the socioeconomic implications of that innovation and may reject the innovation as a result. Similarly, if there are no opportunities for experimentation or access to accurate knowledge about the innovation, then local stakeholders and potential users may not consider the innovation as they do not perceive it as being applicable to them. However, if these features are provided openly and transparently, it is understood that the innovation is adaptable and as a result, has the potential to generate mutually beneficial sociotechnical outcomes.

3.6. Social Acceptance and Agrivoltaics

Social acceptance perspectives have long been applied to renewable energy transitions (see, e.g. Cousse, 2021; Liebe & Dobers, 2018 Ricci et.al., 2008); however, they have only recently been applied to the field of agrivoltaics (see e.g. Pascaris et.al., 2021; Trommsdorff et.al., 2022). Only a few papers have been found as of writing that apply this lens to agrivoltaics, suggesting a growing interest but also that further attention is needed. Ketzer et al., (2020) and Torma & Aschermann-Witzel, (2023) evaluate pilot agrivoltaics installations located in Western Europe and North America and acknowledge the use of various assumptions and hypotheticals. While they have found that social acceptance is reliant on specific conditions pertaining to land use, not unlike the wind farm cases, community responses to the systems are purely based on hypotheticals rather than real-life experiences. Thus, the participant responses highlight the acceptability, rather than acceptance, of agrivoltaics. Further, while every energy system is inherently context-based, the regional sociopolitical and cultural influences on agrivoltaics acceptability cannot be applied to other contexts, emphasising the importance of further research. The following section will discuss the existing research on social acceptance and agrivoltaics while identifying the limitations and gaps that require addressing.

Ketzer et.al. (2020) take a systems dynamics approach to evaluating agrivoltaics in Germany. Using this approach, the authors developed a Causal Loop Diagram (CLD) to map the interlinked factors, arguments, and conflicts observed in agrivoltaics development. The authors stipulate that this method assists in the production of a comprehensive policy recommendation for the sustainable implementation of agrivoltaics and argue that 'knowledge dynamics' allow for better planning and collaboration between stakeholders (Ketzer et.al., 2020: 2). While their research was based on workshops that began before and after the development of a pilot system in Germany, most results discussed in the paper focus on hypothetical discussions that occurred in these meetings. For instance, stakeholders were concerned about the potential visual impact of the agrivoltaics system, mirroring concerns of potential users for traditional ground-mounted solar (Schröter et al., 2023). However, when asked about how this might be mitigated, the participants made some suggestions but were unsure how accepting they would be of the results due to the inability to know for certain what their emotional response would be in actuality (Ketzer et.al., 2020).

In a similar study, Schröter et.al. (2023) conducted an eye-tracking experiment to evaluate stakeholder perceptions of agrivoltaics based on visual impact. This research was also based on the presentation of system mock-ups showing different configurations (e.g. hypotheticals), and they concluded that the participants' opinions on agrivoltaics do not significantly change (Schröter et.al., 2023). These results indicate that stakeholder perceptions may be based more on initial emotional response to the technology development rather than through knowledge diffusion. However, due to this study's relatively small data pool, specific European geographic focus, and conjectural approach further research would need to be undertaken to substantiate this claim.

In addition, for the creation of Ketzer et al., (2020)'s model and due to the nascence of agrivoltaics research—even more so in 2020 than today (2024)—the authors had to make assumptions about the agricultural and technical system, as well as the general acceptance based on these workshops. Their results reiterate the importance of co-production with stakeholders from multiple contexts and backgrounds (Ketzer, et al., 2020). While Ketzer et al., (2020)'s model might be transferred to other temperate regions with similar institutional enabling environments and social understanding of renewable energy innovations, and Schroter et al., (2023)'s findings provide a baseline for how stakeholders view agrivoltaics developments prior to adoption, the applicability of these frameworks cannot be directly applied to an Indian context. Rather, they highlight the importance of further field-based research on the implications of agrivoltaics, not just in India, but other climatic, institutional, and sociocultural contexts as well to develop a more robust understanding. Nevertheless, the attention to the ways in which systems interact during the implementation of agrivoltaics is an important contribution to the literature.

Torma and Aschermann-Witzel (2023, 2024) have introduced two interesting perspectives on agrivoltaics to help understand its social acceptability. In 2023, they applied innovation diffusion and social acceptance as theoretical lenses to evaluate the perceptions of different stakeholders from Germany, Belgium, and Denmark. From the workshops undertaken as part of their qualitative research, interesting opinions on agrivoltaics were laid out, many of them backed by existing literature. Participants were worried about potential conflicts of interest as farmers might opt to prioritise energy generation over crop production; some participants were impressed by the flexibility and adaptability potential of the technology; and others highlighted the importance of access to information. Other opinions outlined in this paper introduced concerns not yet examined specifically in an agrivoltaics context. Some participants questioned the sustainability of agrivoltaics, including soil contamination and end-of-life disposal and/or recycling potential (Torma & Aschermann-Witzel, 2023). Further, some sceptical perceptions were recorded, as one farming participant was unclear on the proper definition of agrivoltaics due to the lack of available information, and other expert participants stressed that agrivoltaics must have a proper and specific definition to protect the technology's 'reputation' from 'pseudo-agrivoltaics' (ibid: 617).

While it was not within the scope of these authors' research of make any claims on what agrivoltaics should be defined as, the inclusion of this expert stakeholder critique and lack of analysis from the researchers emphasises both the need for more research on agrivoltaics to produce a better picture of what the technology is, but also for knowledge exchange purposes. This participant echoes perspectives common in agrivoltaics research (see agrivoltaics section above) that stresses the need for a specific definition, without room for flexibility. However, innovation is a dynamic process and requires translation, rather than direct transferring (Glover et.al., 2019). Therefore, an understanding of what agrivoltaics is 'supposed to be' in Europe cannot be directly applied to the range of possibilities in other regional, climatic, and sociopolitical contexts. The novelty of agrivoltaics lies not only with its innovative symbiotic potential, but also in the ways that it can be adapted to new environments by farmers and other local stakeholders in 'unexpected ways' (Liu et.al., 2020: 315).

In addition, Torma and Aschermann-Witzel (2024) introduce the sociological concept of 'personas' to generalise findings on the social acceptance of agrivoltaics, based on interviews undertaken in Western Europe. While their approach is novel and certainly has the potential to help spread awareness of agrivoltaics in multiple settings, they acknowledge that their research was limited by white, male European bias and the hypothetical nature of their research that does not indicate 'actual acceptance or adoption behaviour' (Torma & Aschemann-Witzel, 2024: 7).

In tandem with the Western European context, research focused on farmer and stakeholder perceptions in North America has increased as well (Pascaris et.al., 2020, 2021, 2022). Pascaris et.al., (2020), for instance, identified three barriers to agrivoltaics uptake, including: 1) end-of-life and post-development impacts on land, soil productivity, and pasture productivity from solar infrastructure; 2) permanent structures interfering with current and future agricultural practices; and 3) uncertainties in operations, management, and business planning that have yet to be fully addressed. Considering these concerns, interviews conducted with solar industry professionals were undertaken to understand steps needed to increase social acceptance of agrivoltaics (Pascaris et.al., 2021). While the industry participants emphasised their support and high expectations for the future of agrivoltaics in the US, the authors concluded that despite community stakeholders being more likely (82% in this study) to accept agrivoltaics over conventional solar energy systems, market success would be contingent upon community participation, a 'fair distribution' of economic benefits for the community, and supportive local regulatory environments (Pascaris et.al. 2021, 2022: 1). Another US-based study, while focused on solar siting but including agrivoltaics as a potential option, interviewed various stakeholders from the industrial to agricultural sectors and determined that farmers are sceptical of such a technological solution and that 'deep upfront collaboration' between stakeholders would be required to enable agrivoltaics (Moore et.al., 2022: 10).

While much literature continues to focus on the Global North, one notable paper analyses the farmer perceptions of agrivoltaics in the emerging economy Türkiye. The researchers' interview questions relied on hypothetical scenarios and did not speak with farmers who have engaged in the technology themselves (Agir et al., 2023) The participants echoed many of the statements above, and the authors specifically highlighted concerns over knowledge diffusion and land competition (Ibid). Nevertheless, this perspective is one of the first from an emerging economy to take a social acceptance approach and reifies common themes in social acceptability of agrivoltaics.

These studies represent the first to examine social acceptability of agrivoltaics and highlight the current disparity in perceptions between industry and community stakeholders. As can be inferred from the literature reviewed in the agrivoltaics section above, researchers and industry stakeholders have a generally positive outlook on the potential of agrivoltaics (Trommsdorff et.al., 2022; Barron-Gafford et.al., 2020). However, as highlighted in this section, social acceptance of local stakeholders is expected to be more conditional. As such, this disparity indicates the need for further research on perceptions and social acceptance, including perceptions based on lived experiences that may differ from assumptions and hypotheticals. Further, while these influential studies shed light on the complexity of agrivoltaics integration and have been derived in part from stakeholder interviews, they remain primarily desk products that draw from previous conceptual work and the frameworks presented have not yet been tested empirically. Each highlights the importance of stakeholder inclusivity and farmer participation throughout the development process; however, they do not include experiential data thus, rendering it less rigorous.

While not applying a social acceptance lens, several studies evaluating the potential social impacts of agrivoltaics have been undertaken in Asia. A study in China determined that farmers had little decision-making power in agrivoltaics development processes and as a result, energy generation was prioritised over agricultural cultivation (Li et.al., 2021). Li et al (2021) echoed previous research on perceptions by concluding that inclusive and deliberative decision-making processes are required to ensure a just introduction of agrivoltaics. Further, a feasibility study on a prospective agrivoltaics system in Maharashtra, India examined both potential economic and social impacts (Trommsdorff et.al., 2022). Based on various modelling scenarios and observed distrust in existing renewable energy systems from farmers, the authors estimated a wide range of potential impacts both positive and negative from agrivoltaics development (Trommsdorff et.al., 2022). Similarly, using a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis, agrivoltaics have been proposed as a method of Climate Smart Agriculture (CSA) for Indian farmers (Mahto et.al., 2021). While this study suggests that agrivoltaics provide significant socioeconomic benefits for Indian farmers, and frames agrivoltaics as an opportunity to meeting global climate commitments for the benefit of national stakeholders, it remains a desk-based study based on existing research, most of which undertaken in Western Europe or North America. Both studies examining the potential for agrivoltaics in India are notable, however their findings are limited by the fact that their findings are based on modelling and educated extrapolation.

Since this remains an emerging field of research, and that agrivoltaics research itself is still in its infancy, it is understandable that there are significant opportunities for further analysis applying a social acceptance lens. Notably, the social acceptance perspective has not yet been applied to established agrivoltaics systems and analysed perceptions based on lived experiences, let alone applied to developments in South Asia. Specifically, the concept of reluctant social acceptance, or the grey area between acceptance and rejection, has also not been applied to agrivoltaics. This may be due in large part to the limited analyses of established systems and lived experiences with them, however understanding the broad spectrum of perceptions of agrivoltaics following its implementation will be crucial. Further, while concerns over long-term implications of agrivoltaics development have been mentioned (Mahto et.al., 2021; Pascaris et.al., 2021), an approach combining social acceptance with an energy justice perspective has not yet been explored in the context of agrivoltaics at time of writing. In the following section, I introduce the concept of energy justice and explore its applicability to social acceptance and agrivoltaics.

3.7. Energy Justice

Energy justice has emerged as a research lens distinct from environmental justice as a method of applying 'justice principles' to energy policy (Jenkins et.al., 2016: 175). As a framework itself, energy justice exists to help evaluate where injustices emerge, which community groups are ignored, and what processes are required to both reveal and reduce these injustices (Khan et al 2020; Heffron et al 2018). It is broken down into three tenants: recognitional, procedural, and distributional justice.

Recognition justice involves recognising that energy resources are inherently unevenly distributed and in so doing can acknowledge that change is required. However, since this uneven distribution can be a result of various forms of 'cultural and political domination' leading to knowledge and infrastructure deficits, recognition justice also requires an acknowledgement of the 'divergent' social, cultural, and political differences within a community or society (Jenkins et.al., 2016: 177). In other words, certain groups may be ignored, disregarded, or misrepresented in development processes and thus their unique perspectives are often missing from policy and regulation frameworks. This includes acknowledging the role of silence as one that does not indicate passive acceptance but rather represents gaps in knowledge and access (Motosu & Maruyama, 2016).

Misrepresenting stakeholder silence as acceptance, however, is an example of recognitional injustice. As renewable energy quickly moves from the periphery to the core of energy policies around the world, insights from a diverse range of groups will need to be included to generate just transitions rather than harmful ones. Significant harmful community-level impacts can result from unjust energy development, including environmental degradation, but also loss of livelihood and perpetual cycles of energy poverty. Thus, recognition justice is highly dependent on the existing government structure and incumbent energy policy that either enables or disregards these factors.

The second tenant, procedural justice, focuses on decision-making and requires 'meaningful participation' from a diverse range of stakeholders, but also impartiality and transparency from governing bodies (Jenkins et.al., 2016: 177). On the local scale, this involves community participation throughout every stage in the development process and full disclosure of anticipated impacts by the developers and decision-makers. On a global scale, this can include knowledge sharing that in turn encourages 'more ethical and sustainable consumption practices' and the acknowledgement of power and capacity imbalances between nation-states, but it can also provide guidelines for 'recourse' if injustices are observed or experienced (Jenkins et al., 2016: 177; Newell & Mulvaney, 2013). Thus, procedural justice is dependent on trust in existing systems based on access to accurate information, knowledge exchange, and the allowance for stakeholders to participate in all stages of development.

Finally, distributional justice is closely related to recognition justice but focuses specifically on acknowledging both the physically unequal allocation of energy resources as well as the uneven distribution of associated responsibilities (McCauley et.al., 2013). Just as renewable energy, and specifically agrivoltaics, are highly spatial technologies, so too is the concept of energy justice when this final pillar is included. Distributional justice examines the 'desirability of the technologies in principle', meaning questioning the almost-unequivocally positive framing of renewable energy, in the context of its multi-contextual considerations related to 'specific localities' (Jenkins et al., 2016: 176; Owens & Driffill, 2008). In other words, this pillar involves interrogating the implications of these systems to the community and calling for an even distribution of both the benefits and consequences for all members of society, regardless of income, race, gender, ethnicity, or an intersection of these and other communities (Jenkins et al., 2016; Heffron et al., 2018). Thus, distributional justice requires us to evaluate the implications of an energy system, including where the technology is installed as well as the associated infrastructure. In addition, it requires examining who has access to the energy system, including the energy produced, and who is responsible for ensuring, or neglecting, that accessibility.

Unlike climate and environmental justice perspectives, energy justice is not always rooted in 'anti-establishment movements' (Heffron et.al., 2018: 168). Conversely, the concept it founded on the pillars discussed above, and often the existence of energy justice is reliant on existing government systems meeting the expectations laid out in these pillars. Climate and environmental justice have been argued as being too broad in their conceptualisations, rendering them difficult targets to both explain and achieve (Heffron et al., 2018). However, unlike these, energy justice is a narrower field with significant focus on economic incentivisation, which renders it easier to understand, and thus more politically palatable, as a concept (Heffron et.al., 2018). It can be argued that this is the case because this economic—or homogenous—conceptualisation of energy justice exists within the current societal and capitalistic status quo. It is the aim of existing energy justice frameworks to be considered in cost breakdowns for energy infrastructure development, thus considering the many economic and environmental costs not currently considered to ensure a more 'equitable distribution' of benefits and costs (Heffron et.al., 2018: 175). While there is significant merit in working towards justice within the current systems as transformative change is highly optimistic, it is important to recognise the disconnect between working to engender social change and reducing injustice within the current system that created those injustices in the first place. Further, as renewable energy innovations continue to be introduced, such as agrivoltaics that may have the potential to be more disruptive than anticipated when allowing for experimentation in new contexts, the pillars of energy justice can and should be adapted to address the systemic changes.

Thus, it is imperative to critically examine this incumbent understanding of energy justice. Each of the pillars calls for active and meaningful participation from the community to produce just energy developments. However, in certain contexts, it may be argued whether meaningful community participation is even possible under the current system of cultural and political domination. Current energy systems are determined by the existing systems that they exist in and are thus highly dependent on government processes and structures. Those that have been historically ignored or whose insights have been devalued due to race, class, gender, or different intersections may continue to be so unless systematic change occurs.

Furthermore, renewable energy, specifically solar, has the potential to change existing systems due to their increasingly decentralised nature (Mulvaney, 2017). This transition will inherently alter existing patterns of development and corresponding policy regulations. Increasingly, energy systems will be available to formerly marginalised communities within the energy participation sphere. That is not to argue that renewable energy is anti-establishment. Renewable energy is capable of being developed within the current status quo—resulting in environmental and sociocultural implications. However, as interventions like agrivoltaics and other decentralised energy systems grow in popularity, it must be recognised that the incumbent systems are shifting to accommodate these innovations. Therefore, when taking an energy justice lens in the context of these kinds of decentralised and renewable energy developments, it is important to remain cognizant of its theoretical roots while also understanding its central aim to encourage 'meaningful global change' may involve systematic shifts as well (Heffron et.al., 2018: 170).

Two additional pillars of energy justice have been introduced to attempt to address these criticisms: restorative and cosmopolitan justice (Dunphy & Lennon, 2022). Cosmopolitan justice acknowledges a 'common humanity' and responsibility to consider wider-reaching implications of actions, offering a method of reframing energy decisions to reflect this (Dunphy & Lennon, 2022: 433; Hazrati & Heffron, 2021; Sovacool et.al., 2016). The aim of this concept is to encourage stakeholders to reflect on the potential local, regional, and global implications of an energy system, from acknowledging the competition for land when siting solar to the unethical sourcing of rare earth metals to manufacture the solar panels. This 'exorbitant responsibility' encourages individuals to critically examine the impacts of decisions, including the ways in which actions intended to foster justice fall short (Clark & Gunaratnam, 2023: 81). An important addition to the field of energy justice, cosmopolitan justice acts as a lens through which to evaluate both the local and far-reaching implications of energy decision-making and thus remains a critical perspective to apply to new technological innovations.

Restorative justice was established to evaluate ways in which to 'repair […and] proactively prevent' harm generated by the energy system (Dunphy & Lennon, 2022; Hazrati & Heffron, 2021).

While this concept originally emerged in criminal justice studies (Wallsgrove et al., 2022), its attention to addressing the harm done to victims can be applied to energy systems as well, with the 'victims' adapted to represent people, society, and/or the environment (Heffron & McCauley, 2017). It is intended to be used to correct existing and preventing new distributional, recognitional, and procedural injustices through governmental, institutional, or other intervention and mitigation strategies (Hazrati & Heffron, 2021). While it has not been conceptualised in such a way previously, disruptive innovations and 'policy mixes' that encourage participation of multiple stakeholder groups, knowledge exchange, and redistribution of resources and responsibilities may fall under the preventing new injustice objective of restorative justice. As a relatively new addition to the prolific energy justice literature, the full applicability of restorative justice has yet to be explored.

3.7.1. *Energy Justice and Renewable Energies in India*

An energy justice perspective has been applied to cases of renewable energy development in India and provides a contrasting understanding of the impact of such developments beyond the accepted positive outlook of energy transitions (Kale, 2014). In the case of a large-scale wind energy development, Lakhanpal (2019) notes that such development is understood differently across stakeholder groups in the Indian context than is shown in most sustainable development and energy transition literature. For instance, local populations understand renewable energy projects to be forms of economic development, whereas politicians and other national actors see them as sustainable development projects, oftentimes for global recognition (Lakhanpal, 2019). However, under this designation, state agencies and private firms have an increased ability to engage in forms of predatory development, often at the expense of local livelihoods, environment, and 'development outcomes' (Lakhanapal, 2019: 56). Further, these projects may even be granted approval to encroach into conservation areas (Lakhanapal, 2019). To boost national profile and meet renewable energy goals, the destructive nature of renewable energy development is often overlooked (Lakhanpal, 2019; Stock & Sovacool, 2023).

In this example, despite obligations to listen to the diverse perspectives, and contestations, of local populations and to justify the project based on its social, economic, and environmental contributions at the local scale to the United Nations, this wind project has resulted in benefits that are 'few and far between' and 'depart significantly' from what the local community members anticipated (Lakhanpal, 2019; Yenneti & Day, 2015). In other words, the benefits of the renewable energy development are felt at higher levels and thus economic efficiency is prioritised in policy, whereas local communities often experience most of the adverse impacts, including reduction in productive land and subsistence capabilities, resource access, and even local self-governance (Lakhanpal, 2019; Best et.al., 2021).

Solar installations in India result in similar concerns. Due to frequent disconnect between national and state-level actors and agencies, resulting in disjointed and uneven energy transition policy amidst incomplete support infrastructure, significant opportunities for injustice are prevalent (Jonnalagadda et al., 2021; Stock & Birkenholtz, 2021; Stock & Sovacool, 2023; Yenneti et al., 2016). Thus far, solar development has taken the form of large-scale installations, despite the knowledge that energy poor households in India would benefit from increased attention to decentralised solar growth (Sareen & Kale 2018).

Instead, the central government utilises the 'wasteland' land designation to reify long-standing colonial and neocolonial governance instruments to obtain land for renewable energy development (Singh, 2022). The use of the term 'wasteland' connotes a sense of unproductivity, the 'political other of value', and frames empty land as an opportunity for 'untapped' economic potential (Singh, 2022: 407). This 'terra nullius' lens has long been applied to India's landscape, having been used to justify colonial 'civilising-enlightening discourses' in addition to the 'post-independence hegemonic modernism' and development processes in place today (Singh, 2022: 407; Baka, 2013). The national prioritisation of 'ecological modernisation in the service of transforming "wastelands" into valuable sites of clean energy' dispossesses marginalised communities in India) of land that was not deemed 'productive' enough (Stock et al., 2023: 5; Singh, 2022).

Further, this process 'radicalises', or others, resource insecure and dependent communities as 'backwards' (Stock, 2020: 374) and in doing so erasing local land use, values, and customs to 'seize' land for renewable energy, including solar, installations (Stock & Birkenholtz, 2021; Stock & Sovacool, 2023). Due to limited access to legal knowledge or recourse, limited ability in Hindi or English (specifically for Adivasi populations that speak officially unrecognised tribal languages), and the physical act of being removed from the land slated to be developed, these communities are excluded from the energy transition (Lakhanpal & Chhatre, 2019; Stock & Sovacool, 2023). Further, these processes other 'resource-dependent populations' (Stock, 2020: 357).

Additionally, the 2011 Census[1] identifies land as 'wasteland', which ultimately skews ideas of the 'perfect' location for solar siting and such data might be used by often, but not always, international developers who have no knowledge of the current systemic injustices in place (Singh, 2022). This contributes to the ongoing dispossession of marginalised communities in India and the growing distrust in renewable energy systems by many, including within the agricultural sector (Sareen et.al., 2018; Trommsdorff et.al., 2021). In fact, renewable energy systems are almost 90% in the hands of the private sector (Singh, 2022: 9, citing Benecke, 2010). In Sareen & Kale (2018)'s study, not a single interview

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[1] The last census completed in India, as the 2021 census was postponed due to the COVID-19 Pandemic. (*The Hindu*, 9 January 2023) https://www.thehindu.com/news/national/explained-impact-of-census-2021-delay/article66358242.ece

participant (n=50) conveyed a ‘sense of conviction’ that ‘ordinary people’ could become involved in solar development and the energy transition (276). Instead, they felt that it was entirely up to the government and regulatory bodies to make decisions on their behalf (Sareen & Kale, 2018). A more recent study found that between two solar park developments in Rajasthan, 93 and 100% of peasants interviewed, respectively, felt that there were ‘no beneficial elements’ evident from the solar development for their communities, and 95.3% stated that they felt they did not benefit from the solar development at all (Stock & Sovacool, 2023: 5).

Distributionally, the most recent census identified that approximately 40% of Indian households were ‘un- or under-electrified’ (Sareen & Kale, 2018). This emphasises the fact that the Government of India’s attention towards achieving 500 GW of renewable energy by 2030 (Government of India, 2023) has not had much effect on electrification efforts nationwide. Rather, it indicates a national bias toward adding energy generation capacity without corresponding investments in transmission and distribution infrastructure (ibid; Singh, 2024).

While decentralised solar policy and uptake has grown in the years since the publication of Sareen & Kale (2018), it is notable that individuals do not feel a sense of ownership or agency over the future of the energy system (Singh, 2024). Indicative of procedural, recognitional, and restorative injustice, this lack of agency provided to individuals and communities ultimately minimises opportunities for experimentation that might disrupt the current unjust ways of renewable energy technological diffusion. The reality that incumbent Indian energy regimes focused on ‘capital accumulation’ perpetuate exploitative practices exemplifies the neo-liberal influences that favour large-scale energy infrastructure and consequently reduce social acceptability of such transitions (Singh, 2024; Stock & Sovacool, 2023: 5-6).

3.8. Conclusion

Increased focus on decentralised energy systems has the capacity to encourage disruptions of existing unjust systems and put more agency in the hands of communities. However, due to the limited efforts by Indian state governments and energy distribution companies (Discoms) to pursue this route, the incidence of large-scale solar developments remains the norm, and the incumbent systems are maintained (Kale, 2014). Even in the case of small-scale solar project uptake, economic results remain policy priorities while equity considerations are not as prominently featured, which limits the opportunities for experimentation and innovation (Best et.al., 2021). Thus, social acceptability of renewable energy remains complex in India. It is yet unclear whether current national policy encouraging decentralised solar has any effect on creating reliable, transparent, and accessible solar energy developments. However, despite these justice concerns, it must be acknowledged that many community groups and individuals do not feel marginalised or lacking agency in the energy transition.

As shall be discussed in the following analysis chapters, farmers in Northwestern India are showcasing significant ingenuity and adaptability to work within the existing sociotechnical system while also potentially exhibiting a way forward to disruption.

Each of these examples emphasise the importance of applying the additional pillars of energy justice to renewable energy development. Specifically, taking a restorative justice approach assists in evaluating the multidimensional impacts of such developments to learn how to correct and refrain from perpetuating them. These studies also highlight the research gap that applies this conceptualisation of energy justice, specifically how it relates to social acceptance and disruptive innovation, to renewable energy in India.

An energy justice perspective has yet to be applied to agrivoltaics literature, including the implications of the technology post-adoption. While agrivoltaics are postulated to provide benefits at multiple scales, the potential to address the three pillars of energy justice let alone restorative justice has yet to be determined. Agrivoltaics are theorised to generate a just transition as stipulated by the three energy justice pillars. The technology can be leveraged to target regions where environmental and climatic change have negatively impacted livelihoods, which may be in marginalised communities as ones at the frontline of climate change, thus potentially meeting the tenant of recognition justice. However, practical research would need to be undertaken to understand the extent. Procedural justice and distributional justice, however, are difficult to quantify in the context of agrivoltaics at this stage due to its emerging nature.

Nevertheless, due to the technology's premise of being co-located on active farmland, significant transparent communication between the agricultural and energy communities must occur for the systems to be built. In addition, noted economic incentives have been established in certain regions to assist in the development of these projects. This would indicate the potential for an existing level of procedural justice. As for distributional justice, further insight would be required to determine the 'desirability' of the technology in principle alongside the lived experiences of these systems in their specific context. If looking solely at existing theoretical literature, agrivoltaics systems are increasing in demand, however evidence of the lived experiences with these systems is limited (Galan, 2022b; Maity et al., 2023; Trommsdorff, Vorast, et al., 2022; Worringham, 2021). While there is potential for agrivoltaics to result in just transitions (Mahto et al., 2021b), there is limited community-level and social science research that examines the role that agrivoltaics systems play.

The application of this energy justice perspective will contribute to the overarching analysis of social acceptance of agrivoltaics. Social acceptability and acceptance are understood as pre- and post-installation perspectives of a technology and constitute a range of affiliated emotions, including acceptance, rejection, apathy, indifference, and enthusiasm (Alexandre, et.al., 2018). This range of perception are encapsulated by the concepts of conditional acceptance (Liebe & Dobers, 2018), referring to the numerous conditions necessary to accept a technology, and reluctant acceptance, in reference to the spectrum of emotions post-installation (Haikola et.al., 2019). As an emerging technology, agrivoltaics have disruptive potential given systems are implemented in conjunction with conditions stipulated by both stakeholders and farmers. Medium, small, and marginal-scale farmers have been disregarded in multiple cases of solar energy developments (Ghosh et al., 2023; Stock, 2023; Yenneti et al., 2016; Yenneti & Day, 2016), but their 'new and unexpected' perspectives may contribute to a successful adaptation and integration of the technology to an Indian context (Liu et al., 2020: 315).

While agrivoltaics have the potential to generate justice, there is limited experiential data based on personal accounts and lived experiences that examine the implications of the technology in practice. Further, a social acceptance lens has been applied to agrivoltaics, however scholars have yet to utilise this approach when evaluating agrivoltaics implementation processes in India. Thus, this research will aim to contribute toward addressing this gap. By applying a social acceptance and energy justice perspective, this research will critically examine stakeholder perceptions of and lived experiences with agrivoltaics in Northwestern India, Delhi and Haryana specifically, to understand the socio-technical configurations and prospects of the technology at the local level.

The following chapters will evaluate results from desk-based document analysis and field research and answer the research questions and objectives posed in Chapter 1 utilising this analytical framework. Utilising social acceptance, disruptive innovation, and energy justice perspectives in this analysis will contribute to producing a more robust understanding of the emerging and evolving perceptions and best practices of agrivoltaics in decentralised and emerging economy contexts, specifically in India. In this regard, the significance of knowledge exchange, farmer participation, flexibility in agrivoltaics conceptualisations, and experimentation to adapt the technology to new contexts will be explored in the following chapters.

However, before analysing the current framings, perspectives, and prospects of decentralised solar and agrivoltaics in India, this project's methodology will be discussed.

Chapter 4: Methodology and Methods

4.1. Introduction

Agrivoltaics is a quickly growing field of research due to its holistic and interdisciplinary potential, but there remains a significant gap in the literature that examines the implications of agrivoltaics in practice. Solar energy is already recognised as a technology that alters patterns of development and repositions power and land dynamics due to its scalable nature and the potential for innovative configurations (Mulvaney, 2017). Agrivoltaics are likewise viewed by analysts as building on this altered relationship as a technology that sits at the centre of the food-energy-water nexus, generating resource security and climate resilience for farmers and local communities (Schindele et al., 2014). However, to further develop agrivoltaics and opportunities for just transitions, the technology must be evaluated at different scales and across different contexts.

The following epistemological framework will provide crucial conceptual background for addressing these questions. Utilising social acceptance, disruptive innovation, energy justice perspectives, this thesis will contribute to a more comprehensive understanding of the impacts of agrivoltaics in practice. To this end, methodologies such as document and policy analysis, stakeholder semi-structured interviews, and photo-visual techniques will be applied to parse the diverse framings, presentations, understandings, and perceptions of agrivoltaics in India, as well as how those perspectives are influenced by implicit socio-cultural and political structures (see Table 1).

Table 1: Overview of the Methods			
Research Question	Data Sources	Collection Method	Analysis Method
How are agrivoltaics presented in policy and what are the implications for the development of an enabling environment for agrivoltaics in India?	Documents and policy reports, etc.	Document analysis Semi-structured interviews	Thematic analysis
What are the drivers, risks, and benefits associated with agrivoltaics development?	Documents and policy reports, etc. Lived experiences	Document analysis Semi-structured and episodic narrative	Thematic and narrative analyses

		interviews Photo-visual techniques and Observation	Content analysis
In what ways do Indian farmers influence, inform, and disrupt the perceptions, innovation, and implementation of agrivoltaics?	Lived experiences Development processes Management processes	Semi-structured and episodic narrative interviews Photo-visual techniques and Observation	Thematic and narrative analyses Content analysis

4.2. Data Collection Methods

To address the research questions and objectives, a combination of primary and secondary data was collected and analysed. The secondary data was utilised to develop an understanding of agrivoltaics policy, regulations, promotions, as well as farmer and other stakeholder (including NGO, research institution, or government staff, academics, and developers) perceptions in India. The comprehensive examination of policy documents, news reports, and other documentation referencing agrivoltaics in India contributes to an understanding of how the technology is presented, promoted, and understood by elite and expert stakeholders. Nevertheless, it was anticipated that the framing and promotion of agrivoltaics in policy documentation will differ from the implementation, utilisation, and evolving perceptions of the technology on the ground. Therefore, primary data collection methods, including semi-structured interviews and photo-visual techniques were utilised to further develop an understanding of how agrivoltaics are not only precepted, but used and might be used in practice.

4.2.1. Document Analysis

I analysed both policy and media documentation through comprehensive document analysis of agrivoltaics in India. I collected documents, from government and developer websites, and informational leaflets and pamphlets to government reports and policy documents. Approximately 40 documents were reviewed during this process, ranging from short news articles to 60-page central governmental policy memos and orders to 172-page reports analysing policy implementation and agrivoltaics pilot projects. Each document was manually coded using NVivo qualitative analysis software, using both conceptual (e.g. justice, rural development, energy goals, etc.) and empirical codes (e.g. lived experiences, motivations, etc.). See Tables 2 and 3 for an Overview of Document and Media Analyses.

I focused my research on India's solar energy system, its generation capacity, locational dynamics and supporting policies, both existing and proposed, including but not limited to those detailed on the website and databases for the Indian Ministry of New and Renewable Energy (MNRE), the Institute for Energy Economics and Financial Analysis (IEEFA), the Indian Council for Agricultural Research (ICAR), as well as other government ministries and research institutes. Solar and agrivoltaics developer websites and brochures from within India were also considered, including those published for government funded organisations, such as those published for the Krishi Vigyan Kendra (KVK) farmer capacity building facilities.

Agrivoltaics are still relatively new, thus there is limited public documentation. Accordingly, I expanded the search to include any documents related to agrivoltaics, such as those discussing other decentralised solar initiatives and general renewable energy policies. Expanding the scope of document research in this way allows for a wider understanding of how solar PV and other forms of renewable energy are framed in different contexts and communicated to different stakeholders. In addition, it was important to distinguish between documents and records, as while records are generally administrative resources, such as census or energy data, the wide interpretation of documents required more contextualised interpretations (Karippinen & Moe, 2012). For instance, while records that include data on energy access and distribution were useful to provide context for the field visits, documents such as policy reports, pamphlets, and media articles have a distinct framing that have different perspectives that could be interpreted.

Studies using document analysis often consider documents as 'part of material culture' and 'sedimentations of social practices', while also having the potential to 'inform and structure the decisions' people make on a daily and longer-term basis (Flick 2012: 356; Atkins 2018). The documents examined in this analysis are informed by distinct perspectives from government decision-makers, researchers, or journalists. Thus, these documents are 'social products […] bound up in [the] discursive power' of the subjective perspectives of their creators, which in turn have the potential to influence viewpoints of its readers (Karppinen & Moe, 2012: 11). Understanding that documents that disseminate information to the public, especially about renewable energy access, are subjective data and therefore have social implications will influence the analysis process was crucial. For instance, considering the audience of each document as well as the potential perspectives of the contributors is necessary for understanding its meaning.

All documents identified and assessed for this thesis were assumed to be influenced by other, historical documents, such as historical and colonial energy provision and electrification regulations and policies. For example, policies or speeches are influenced such that they 'document and construct social realities', meaning that culture and socio-politics influence the viewpoint, or frame, of the document itself (Flick, 2012: 356; Bowen, 2009; Singh, 2022). A critical analytical approach was applied to this method to understand how these socio-political structures influence the presentation and framing of agrivoltaics in documentation. In turn, these perspectives are expected to influence how agrivoltaics is perceived among different stakeholder contexts.

Table 2: Document Analysis Overview

Title or Source	Quantity	Pages
PM-KUSUM Policy Documents (including Memo updates and guidelines), (2019-2022), Ministry of New and Renewable Energy (MNRE), Government of India (GOI)	12	119
Grid Solar Provisions (2019), Letter to Developers (2019), Grid Connected Rooftop Solar Policy, Ministry of New and Renewable Energy (MNRE), Government of India (GOI)	3	33
Agrisolar Best Practices Guidelines, India Edition (2024), NSEFI (National Solar Energy Federation of India)	1	50
Fraunhofer Institute for Solar Energy Systems (ISE) DIN-SPEC 91434 Agrivoltaic Regulations (2021)	1	25
European Commission Agri-photovoltaics Policy Brief	1	4
Indo-German Energy Forum (IGEF) Feasibility and Economic Viability of Horticulture Photovoltaics in Paras, Maharashtra (2019)	1	112
Indo-German Energy Forum (IGEF) Legal Aspects of Agriphotovoltaics in India	1	172
Implementation of Scheme for Solar Parks and Ultra Mega Solar Power Projects (2014-15), Ministry of New and Renewable Energy (MNRE) Government of India (GOI)	1	13
Guidelines for Tariff-Based Competitive Bidding Process for Procurement of Power from Grid Connected Solar PV Power Projects (2017), Ministry of Power, GOI	1	31

TIGR^{2}ESS (Transforming India's Green Revolution by Research and Empowerment for Sustainable Food Supplies) Report, (2022) UKRI, University of Cambridge, ICAR-IARI	1	46
Agrivoltaics in India (2023), IISD	1	41
Implementing Solar Irrigation Sustainably (2023), IISD	1	122
Agrivoltaics in India: Overview of Projects and Relevant Policies (2023), NSEFI (National Solar Energy Federation of India)	1	87
Totals	26	768

4.2.1.1. Policy Analysis

Policy analysis can function as a subset of document analysis and involves the critical and comprehensive examination of policy and regulatory documents pertaining to a specific subject, in this case agrivoltaics (Bowen, 2009). Documents including policy documents, reports, leaflets, and other texts designed for public consumption focused primarily on solar and agrivoltaics development in India have been examined (Pulipaka et al., 2023, 2024; Rahman, 2023; Worringham, 2021). Where such documents were inaccessible or not published in English, feasibility studies and policy reports focussed on the potential success of agrivoltaics projects in India were examined in their place (Trommsdorff et al., 2022; Patel et al., 2019). While cross-national comparison of agrivoltaics was originally considered due to the technology's nascency, it was deemed beyond the scope of this research's primary focus of agrivoltaics' existing installations and future potential in India. Further, the perception and understanding of agrivoltaics at the community level in India may differ from the perceptions of the technology in Germany or Taiwan based on socio-cultural contexts (Worringham, 2021). Thus, it was imperative that no assumptions were made by me regarding India. While agrivoltaics may be framed in a similar manner at the national level to other country or regional contexts, the implications of such policy are likely to be shaped by contextual factors, including the community perceptions and acceptability of agrivoltaics. Thus, I prioritised an analysis of policy documentation focused on the Indian context.

4.2.1.2. Media Analysis

Media analysis is another subset of document analysis; however, the material is more focused on the subjective rather than objective facts. Newspaper articles, magazine articles, and other grey literature, or texts that have not been peer-reviewed, have been consulted during this process. The media documents analysed were focussed primarily on the Indian context, leveraging primarily English-language Indian news publications but also exploring international publications as well. Distinct framings present in articles published in Indian media versus international sources when discussing the emergence and implications of agrivoltaics in India are expected to exist. However, by comparing media from both Indian and international sources, a clear understanding of the multiple frames and presentations of the Indian agrivoltaics market and future can be derived.

Overall, the document analysis process contributes to identifying the ways in which agrivoltaics are framed and how those frames might influence social perceptions of the technology. Existing literature indicates climate mitigation and economic co-benefits framings; however, it is expected that more diverse perspectives will emerge in this novel context due to several factors including but not limited to the reduced access to information about agrivoltaics (Miao & Khanna 2020; Barron-Gafford et al., 2019). Identifying the different ways in which agrivoltaics can be framed will be essential to understand the drivers and barriers of agrivoltaics adoption and development, by a range of stakeholders. Drivers of renewable energy development are especially linked to the perceived benefits of participation and engagement and barriers are equally influenced by perceived risk (Cousse, 2021; Stigka et al., 2014). Therefore, potential benefits and risks emphasised by literature, such as resource security or financial risk, respectively, will be further contextualised by the documentation that influences those perceptions.

As noted, all documents contain a particular viewpoint and thus have a subjective agenda that must be considered throughout data collection and interpretation. Thus, a comprehensive and critical analysis of the discourse, including the use of language and sociopolitical influences, was conducted to examine how agrivoltaics are framed to either encourage or discourage acceptability.

Table 3: Overview of Media Analysis		
Source		Quantity
Counted by source not individual webpage or publication	Government of India (GOI) Publications, including: Ministry of New and Renewable Energy (MNRE), Ministry of Agriculture, Ministry of Environment, Forest, and Climate Change	3
	Additional media sources including: India Times, Reuters, Mercom India, Economic Times, Sun-Connect.org, Asian-Power.com, PV-Magazine, One-Earth.org	8
Total		11

4.2.1.3. Limitations

Limitations of document analysis include but are not limited to essential data potentially being forgotten or omitted, such as in developer promotional materials; vagueness in certain documents, such as in government reports; potential for bias, skewing, or omission in documents where the data is collected by someone else, or another agency; and language barrier. Since the only documents I can access are those written in English, there is the added risk of missing out on potentially valuable information written in Indian languages, of which there are several hundred. This limitation is especially true for local resources, such as local government and research institute pamphlets, speech transcripts, or newspapers, but it can also relate to developer promotional materials aimed at local communities. It will also be likely that some documents may seem important at the beginning of the process but may not actually be applicable in the analysis phase.

Nevertheless, there are mitigation strategies for each of these limitations, including constant maintenance of reflexivity and awareness of my positionality as a researcher by acknowledging my potential for bias in the analysis phase. This awareness involved recognising when my worldview or experiences coloured my interpretation of transcripts and documents and adjusting accordingly. Moreover, some documents may have English translations available or can be made available. For instance, government websites and resources are generally in both Hindi and English, and English language newspapers frequently translate older articles. However, I remained reflexive of how frames and discourses might shift between translations. In addition, to overcome the risks of document analysis, I should always consider what has (potentially) been left out in the production of this document, by whom and for what purpose. For example, considering the social or socio-political circumstances that may have influenced decision making will be key.

4.2.2. Interviews

Primary data collection involved semi-structured interviews with a variety of stakeholders and decision-makers at the national, regional, and local levels. Semi-structured episodic narrative and walking interviews were conducted with those who are actively engaged with decentralised solar and agrivoltaics installations, including farmers, farmer extension programme staff, NGO and community-facing organisations, developers, researchers, and policymakers. Fifteen individual interviews were conducted, lasting approximately 45 minutes to one hour in length. One interview involved multiple participants due to its walking interview structure, as multiple farmers were present. Walking interviews are further discussed in the following sections.

Semi-structured episodic narrative interviews allow for additional flexibility in an interview setting and involve asking a participant to provide a personal account or experience related to a specific topic (Silverman, 2014), in this case their experience living and working with agrivoltaics. Semi-structured interviews involve preparing questions before the interview while allowing for flexibility to 'explore pertinent ideas' that may arise during the interview to understand the participant's 'unique perspective' rather than a 'generalised understanding' (Adeoye-Olatunde & Olenik, 2021: 1361; McGrath, et al., 2019). This type of interview structure with key community members, farmers, and other stakeholders provides useful contextual background while capturing lived experiences to provide a 'richer' account that sheds light on the implications of the agrivoltaics development process on a personal level (Flick 2014: 267; Silverman 2014). Episodic narratives are distinguished because only lived experiences surrounding agrivoltaics installation, including motivators for development and perceptions throughout the process will be the central focus of the analysis. Hence, only the 'episode' of a participant's experience with agrivoltaics or solar development was considered.

Further, narrative interviews allow for a detailed account 'unobstructed' by the interviewer and allows for follow-up questions after the account that is based on the narrative rather than any preconceived notion or bias that may 'obstruct' or influence it (Flick 2014: 270-2). In other words, 'mini stories' were sought by asking one question to begin with, such as 'tell me about your experience during the development phase' followed by any probing follow-up questions if necessary. This allowed for the most unobstructed account allowed by my positionality as an outside, foreign researcher as possible (Brown, 2023; Flick, 2022). While there are limitations of seeking episodic narratives in interviews conducted in Hindi through an interpreter, this method was utilised to compare different perspectives of agrivoltaics installations, best practices in development processes, diverse configurations, and community-level implications of the systems with care and limited bias. Thus, these interviews shed additional light on the reality of current agrivoltaics projects and the feasibility of future implementation at smaller scales, as would be necessary for scale-out in India[2].

Most existing literature on agrivoltaics engages a more optimistic tone highlighting innovation and potential socio-economic benefits the technology is designed to provide (Worringham, 2021). Therefore, it can be assumed that national stakeholders in India may use striking buzzwords in documentation to encourage positive perceptions of agrivoltaics installations and subsequent adoption.

[2] Please see Appendix A for the full list of interview questions distinguished by participant type: national stakeholders, experts and developers, and farmers and community members; and photo-visual prompts. In order to streamline the interview process and for better cross-lingual understanding with farmers and local stakeholders who preferred to speak in Hindi, it was recommended that my original questions be made more direct and translated into Hindi. These updated questions are available in Appendix B.

However, gaining insight to lived experiences with developing policy and implementation processes through interviews may shine a more realistic light on the implications of agrivoltaics development.

4.2.2.1. Expert and National Stakeholder Interviews

Semi-structured episodic narrative interviews with academics, civil servants, developers, and other experts who are informed on, or have participated in, agrivoltaics installations or policy development, specifically focused on the Indian market were conducted. Semi-structured interviews allow for flexibility with a more conversational style therefore questions, comments, and general themes were prepared in advance. However, additional topics or avenues of discussion that open in the moment were anticipated. These interviews allowed for additional and specific insight into the entire decision-making process, including but not limited to perceptions of the technology, existing government incentivisation mechanisms, drivers and barriers to involvement, and outlook on the future of agrivoltaics from a decision-making perspective.

Interviews were conducted with national policymakers who have participated in the development of an incentivisation scheme for decentralised solar that briefly discusses agrivoltaics. Experts at New Delhi-based research institutions who have conducted comprehensive economic analyses of agrivoltaics and produced a Handbook for this incentivisation scheme, and thus agrivoltaics, for developers, farmers, and other potential stakeholders were also consulted. In addition, staff at nongovernmental organisations that have facilitated small-scale agrivoltaics development and other agroforestry techniques were contacted.

4.2.2.2. Interviews with Farmers and Community Members

Semi-structured episodic narrative interviews were also conducted with community members, farmers, and other local stakeholders, such as participants from NGOs or other capacity building initiatives, to determine perceptions of agrivoltaics based on their lived experiences and interactions with the technology. Interviews were conducted with community-facing organisations, including organisations focused on facilitating solar-powered irrigation pumps, and capacity building in Adivasi (Indigenous), tribal, and other rural, marginalised communities. In addition, interviews were conducted with local partially government-funded farmer capacity building organisations, Krishi Vigyan Kendras (KVKs), which provide knowledge, trainings, and workshops on new innovations and techniques for farmers. When examining lived experiences with agrivoltaics, it is imperative that community perspectives, from organisations working directly with agricultural communities to the farmers themselves. Walking interviews were also conducted to provide a greater sense of place and ease for the farmer participants.

4.2.2.3. Walking Interviews

Walking interviews are conducted on the move as a method of understanding the relationship between what is said and where it is said (Evans & Jones, 2011) as well as providing a sense of ease for the participant by alleviating a degree of pressure inherent in sit-down interviews (Kinney, 2017). Wherein most farmer participants' interviews were conducted in Hindi using an interpreter, the additional sense of comfort provided by the walking interview method facilitates more open responses and comfortable discussion. Walking interviews provide interesting insights on perceptions of agrivoltaics because it can be noted where a participant may choose to speak on a topic, such as highlighting a certain aspect of the installation and their opinions on it. As agrivoltaics are inherently place-based, this method of interview contributes to generating a richer understanding of place and the participants' experiences (Evans & Jones, 2011).

Some additional considerations had to be made in the field during these interviews, including opening-up the planned single participant semi-structured interview to a group semi-structured interview. When visiting the farm for the purpose of speaking with farmers, rather than stepping forward one at a time, it became more time and resource efficient to speak with them as a group (Frey & Fontana, 1994). This shift in methodology allowed for more comfort and organic conversations between the farmers as they brought their perspectives to the prompted questions and reminded each other about anything that might have been left out. As farmers who collectively cultivate the land under the agrivoltaics panels, their perspectives were generally aligned, but how they worked through each question together through open discussion provides additional insight that otherwise would not have been achieved had the interviews remained one-on-one. Understanding lived experiences with agrivoltaics includes understanding how the system was introduced, the development process, the level of community involvement within the decision-making process and to what extent, and information on the systems' governance, which may include a measure of energy, crop production, and water efficiency, if they are being measured.

Conducting semi-structured episodic interviews with agrivoltaics developers, government elites, and experts allow me to obtain 'objective "facts" [while] eliciting authentic accounts of subjective experience[s]' in relation to how the agrivoltaics system was developed (Silverman 2014, p.174). These 'facts' described in interviews with key decision-makers and stakeholders are acknowledged to possess a degree of bias as these stakeholders have specific perspectives of the technology and implementation processes. Thus, these perspectives will be compared with the narratives and lived experiences provided by farmers and community members who can elaborate on the ground realities of agrivoltaics systems.

Common themes identified through the comprehensive literature review and document analysis were built upon to inform interview questions for key stakeholders, experts, and farmers as well as inform conceptual and empirical analytical codes. The aim of the interview process was to discern the genuine development process in comparison to how it is described and presented in literature and documentation. These interviews contribute to a greater understanding of the socioeconomic and political implications of agrivoltaics implementation based on varying degrees of community participation, capacity building, and socio-technical configurations. This examination of Indian agrivoltaics, while a small sample size, lends crucial insights to future developments in similar climatic, community-based, or emerging economy contexts.

4.2.2.4. Limitations

Limitations for narrative episodic and semi-structured interviews include a high rejection rate and assumptions of truthfulness, when aspects may be misremembered, misconstrued, or left out entirely (Flick, 2022; Liamputtong, 2022). Similarly, participants who speak in a dialect was considered. This language barrier and subsequent interpretation may omit or 'rewrite' certain aspects of the narrative, which may impact the presence of certain themes or nuance. To mitigate this risk, a 'foreignised' translation was sought to understand the participant's meanings in their own context, thus preserving local terminology where possible even if it does not produce a polished text (Smith, 2012: 163; Brown, 2023). This includes leaving in local slang without attempting to directly translate and losing the wider cultural significance in the process. In doing so, this method of translation does not assume that the interpreter is an invisible, unbiased presence, but rather an active participant in the data collection process. A doctoral candidate based at my host research institution in New Delhi with experience researching decentralised solar and with knowledge of local northwestern Haryana Hindi dialect volunteered to provide this crucial interpretation work. While this indigenisation of the text was expected to influence to also influence perceptions of nuance, it also provides important socio-cultural insight and context. In addition, due to time constraints of both me and my host research institution (ICAR-IARI) and the farmers themselves, paired with a language barrier and the consequent necessary need for interpretation lengthening the time commitment, the consolidation and translation of interview questions became necessary. Therefore, a shorter list of key questions was identified to prioritise (see Appendices).

Furthermore, while it became time and resource efficient to transition to a group interview setting with some farmers, my presence along with staff from the organisation that facilitated their agrivoltaics system may have influenced the level of detail and condor in the farmers' answers. Nevertheless, the recognition of power dynamics at play during the group interviews generates an interesting critical angle to pursue during subsequent analysis.

To overcome the limitations of the interview process, contact pools were expanded for participants to leave room for rejection while also ensuring that there remains a robust group of participants. In addition, remaining reflexive and acknowledging the extant limitations of data collection will be crucial in analysis and discussion. It was also possible to leverage assistance from a colleague who is familiar with the language to provide basic proofreading of the translated interview transcripts. However, it was important to consider the ethicality of sending interview transcripts to a third party to compare for accuracy in translations.

Furthermore, it is crucial to acknowledge that only using conceptual codes lifted from the literature may lead to tunnel vision in analysis. Thus, empirically driven codes derived from document analysis and through identifying common themes in primary data in conjunction with concept-driven codes were utilised. Remaining reflexive and keeping a strong track of codes and findings has contributed to mitigating this risk.

Additionally, the language barrier, time limitations not allowing for embedment within the community, and potential for bias within documentation and translation services remain risks. While many interviews with government officials, developers, and academics were conducted in English, as one of India's official languages, translation services and interpreters were required for community interviews and transcription. Acknowledging that the presence of potential bias in the translation as I was not able to verify was key. The recognition of this limitation was expected to impact my subsequent interpretation due to the nature of data I have gathered. There are additional ethical considerations that must be made while conducting research using interpreters and translation services, including but not limited to bias and nuance being lost in translation. Ultimately, translation is a lengthy process that involves back and forth between the researcher and the interpreter to ensure that the most nuanced, culturally accurate text is produced for analysis.

4.2.3. Photo-Visual Techniques

Photo-visual techniques are used in qualitative research as a method of decentring the researcher using photographs in interviews, with photovoice and photo-elicitation recognised as two common methods (Gabrielsson et al., 2022; Hergenrather et al., 2009). Photo-visual techniques use photographs to allow for the participants to interpret or respond to prompts or questions in their own way, thus increasing reflexivity within the research and reducing the potential for researcher bias when working in a community setting (Copes et al., 2018). For instance, photovoice allows for participants to take photographs themselves based on prompts given by the researcher while reducing the risk of researcher influence due to increased independence of the participant to interpret the prompts however they see fit (Gabrielsson et al., 2022). While utilising the photovoice method, the researcher becomes a spectator and it allows for the participant to present themselves, their community, and their experiences in their own way, such as through the creation of a photographic diary, without language existing as an added barrier (Hergenrather et al., 2009). Alternatively, photo-elicitation involves using photos within an interview setting to break the ice and prompt responses or narratives based on the image (Kyololo et al., 2023). While these techniques are utilised to centre the participants and increase reflexivity, it is notable that the subsequent analyses of the images captured by the participants, or their accounts based on images is evaluated by the researcher and subject to specific positionality and inherent bias. Nevertheless, photo-visual techniques are useful for overcoming language barriers and highlighting participant viewpoints.

Photo-visual techniques, including photo-elicitation and a modified photovoice methodology, were employed to facilitate and maintain this level of reflexivity and participant participation during the interview process (Kyololo et al., 2023). Photo-elicitation was employed when speaking with participants utilising decentralised solar other than agrivoltaics, such as solar pumps. While photovoice involves asking participants to take photographs themselves and submit them to the researcher, this involves a longer time requirement to allow for the dissemination and subsequent return of cameras and photographs that was not possible in this case (Sutton-Brown, 2014). Due to time constraints, I asked participants to direct my photographs in response to my prompts during the walking interviews. This method, while modified, still highlights participant voices, perceptions, and experiences without language barrier (Copes et al., 2018; Richmond & Lahman, 2014).

Photo-visual content analysis was also employed following data collection, however this analysis ultimately dependent on the perspective of who took the picture and the subject. Thus, the photos were analysed through the lens of the question the participant was tasked with answering and applying thematic codes where possible. Despite I, as the researcher, took the photos, I was nevertheless directed by the participant and the resulting photographs provide another perspective of the agrivoltaics systems.

Limitations for photo-visual methods include technical literacy concerns, time constraints, and importantly, whether the images tell the 'full truth' (Kyololo et al., 2023). If photovoice methodology had been used, participants would take the photos themselves and they may choose to not show the downsides of the agrivoltaics system development, which would lead to skewing of the data. In addition, it would require a longer time commitment, as at least two meetings per participant would need to occur (Sutton-Brown, 2014). In response to these concerns, photo-elicitation was the most time efficient. Photo-elicitation and the modified photovoice technique also addresses technical literacy concerns. This maintains the photo-visual method as a participatory one while also reducing the time commitment and additional ethical considerations necessary when providing participants with equipment.

Finally, content and thematic analysis allowed for an examination of how participants interpret the agrivoltaics systems and photos of the site, or similar developments, by identifying repeating or similar themes in transcripts and images (Sovacool, et al., 2023; Aslam & Rana, 2022). Similar to thematic analysis, a qualitative content analysis that involves coding recurrent images presented in the visual data has been employed and compared with interview data (Silverman, 2014). Visual data can be conceptualised as text to be analysed and interpreted, and thus discourse and thematic analysis can be applied (Sutton-Brown, 2014; Flick, 2012). Thus, the foci of the photographs taken when touring the site and the foci of photographs directed by participants can be compared. Content analysis is the most effective in the instance of the modified photovoice technique because common images or points of focus identified as important to the participant may be analysed. The most efficient method of collecting photo-visual data was to employ this method in tandem with walking interviews with participants, and the participants were provided opportunities to indicate aspects or scenes that should be captured.

The above-mentioned methods contribute to the generation of a collective story understanding the interacting processes for agrivoltaics development. This story was subsequently analysed based on how the different narratives, photos, and documents interact with each other. This will help create a robust picture of the agrivoltaics systems' development processes, stakeholder perceptions, effective socio-technical configurations, and potential future roadmaps for implementation. Further, this method allows me to examine the way participants' experiences, and what they choose to highlight, interact with the current discourse surrounding agrivoltaics.

Table 3: Overview of Interview Participants and Extent

Interview Participant(s)	Interview Type	Number of Interviews
Expert and National Stakeholders	Semi-structured episodic narrative interviews Approximately 1-1.5 hours in length	3 interviews (3 participants total)
NGOs	Semi-structured episodic narrative interviews Approximately 1-1.5 hours in length	3 interviews (3 participants total)
Farmers and KVKs	Semi-structured episodic narrative interviews Approximately 1-1.5 hours in length Language Interpretation often needed	4 interviews (6 participants total)
	Walking interviews with photo-visual techniques Approximately 1.5-2 hours in length Language Interpretation often needed	3 interviews (6 participants total)

4.3. Sampling

I employed a combination of snowballing and purposive techniques to select and reach 18 interview participants (Palinkas, et al., 2015). Contacts at several institutions in India, specifically the Indian Council for Agricultural Research - Indian Agricultural Research Institute (ICAR-IARI) in New Delhi have offered support in the field facilitating meetings with experts, politicians, and farmers. The contacts made through existing ICAR-IARI networks facilitated interviews with KVKs, farmers, and decentralised solar site visits that would otherwise not be possible. In addition, NGO contacts assisted in providing not only proxy interviews by speaking on behalf of marginalised rural communities that participate in agrivoltaics and decentralised solar schemes but also providing outreach to community members and developers. Finally, cold emailing, or researching other potentially relevant organisations and reaching out via their contact email on their webpage provided additional opportunities for speaking with additional NGO stakeholders. See Table 3 for an overview of the interview participants and extent.

As a foreign researcher relying on connections my few existing contacts in India had to reach participants, it was difficult to arrange, organise, and execute my field work. Requiring both extensive immigration and academic permissions from the Government of India, it took considerable time and effort to negotiate the time and length of my visit, which was shorter than initially anticipated. Thus, the number of participants, particularly farmers, I met with was more limited, as initial contact with them was only possible once I was in India. In addition, a degree of flexibility was crucial in the field, as certain planned meetings did not go forward but new opportunities with other stakeholders also presented themselves, including organising virtual interviews after returning from my field work. Interviews were conducted both in person during my field visit for the month of September 2023 and online via Zoom between August 2023 and February 2024.

Most participants have asked to remain anonymous, thus I chose to anonymise all of the participants' identifiers. For example, NGO staff are identified as NGO 1, NGO 2, etc. and refer to different organisations not simply different employees within one organisation. Farmers are identified by the type of solar they interact with, for example, agrivoltaics farmers are identified as AVS 1 or AVS 2, and solar irrigation pump farmers are identified as SP 1, SP 2, etc. For farmers, these identifiers apply to each site, even if the interview involved multiple participants. All other participants are identified by descriptors such as Researcher, GOI Employee, and AVS Developer.

4.4. Analysis

Following data collection, the interview transcripts were transcribed and edited. Any interviews conducted in Hindi were translated and transcribed with the assistance of a fellow PhD student based at ICAR-IARI with experience researching decentralised solar. Both thematic and critical discourse analyses were utilised to identify, examine, and interpret patterns in documentation and personal experiences. All interviews were coded by hand during the first pass over the transcripts and manually and automatically coded using NVivo qualitative analysis software. Both concept and empirically driven codes were employed in this analysis, as both existing literature and collected data influenced which codes are important. Some conceptual codes derived from preliminary research and document analysis include but are not limited to: (in)justice, empowerment, and social acceptance. Some empirical codes derived from data include but are not limited to opportunities, risks, resource (in)security, and what is not said. Evaluating what is not said applies to intentional or unintentional omissions, but also implicit circumstances or structures that influence perceptions.

4.4.1. Case Studies

A case study approach was utilised in this research to focus on the specific region of northwestern India, as well as produce results and analysis that were theoretically and thematically transferable. While some scholars critique case studies as not being generalisable in the same manner of quantitative analysis (Hägg & Hedlund, 1979; Gibbert & Ruigrok, 2010), others argue that qualitative case studies have merit in terms of theoretical transferability and can provide crucial context for further empirical studies and generalisation (Tsiang, 2013). Thus, while a relatively small sample size was investigated over the course of this study, by critically examining the recurring topics and discourses utilised by participants and documentation, overarching themes could be parsed and have the potential to be considered and applied in future research.

4.4.2. Thematic Analysis

Thematic analysis is recommended by existing methodology literature to work in tandem with other qualitative methodologies, such as interviews and critical discourse analysis, to keep the analysis grounded and focused (Mulvaney 2017; Chatti et al 2017; Howarth 2010). Essentially, thematic analysis provides a roadmap that the other methodologies will be able to follow. It also works well in a case study setting as it produces themes that can be compared across the cases to render the search results transferable following completion of the project (Smith 2012). All documents and interview transcripts were first manually coded and uploaded to NVivo qualitative analysis software for further passes to identify themes and patterns in the text pertaining to agrivoltaics implementation and lived experiences.

Since there is minimal research on the community-level implications of agrivoltaics, the results gleaned from this thesis will contribute to filling this gap and through thematic analysis may be rendered transferable, but not generalised, to help inform agrivoltaics development considerations globally. Agrivoltaics research cannot be generalised and consequently rendered ineffective due to the inability to apply any specifics to new installations in different contexts. Alternatively, the identification of common themes such as the implications of agrivoltaics installations on resource and livelihood security and just processes lend transferability to new contexts. Although the results of this thesis will be focused on the Indian context, the broad strokes and thematic considerations will nonetheless apply to other contexts and environments, especially those outside of Western Europe and North America.

4.4.3. Critical Discourse Analysis

The existing pool of agrivoltaics research consists predominately of practical studies in the Global North and literature with a Global South focus has, at the time of writing, been limited to feasibility studies. Critical engagement with the personal experiences with the systems has yet to be published. Despite India's position as a global leader in decentralised solar and agrivoltaics pilot project development, a critical examination of agrivoltaics extracted from lived experiences across multiple stakeholder groups while also considering the influences of the complex colonial history of electrification and energy access on India's solar transition has not yet been attempted.

Therefore, by identifying the existing frames extracted from the thematic examination of agrivoltaics from such documents, I evaluated how the existing discourses that are themselves informed by historical and sociocultural context impact and influence perceptions and development of agrivoltaics in India. Discourse analysis is understood as the 'study of language-in-use' by examining the 'socially-constructed realities' within which we communicate (Hajer & Versteeg, 2006: 176) Critical discourse analysis is deployed to investigate the ways in which language impacts, influences, and is influenced by, and relates to the social realities of access and empowerment (Kivle & Espedal, 2022; Flick, 2012). Categorising discourses is a method of understanding the world, while also recognising that worldviews are inherently subjective (Kivle & Espedal, 2022). Discourses in this context involved identifying and analysing the different frames of agrivoltaics presented in documentation and their influence on social perceptions. It will also assist in critically examining how social acceptance, innovation, and justice intersect with language and socio-technical configurations in agrivoltaics development pathways.

In analysing the discourse of a text, the researcher is injecting subjectivity and reflexivity into the text. The method can be rooted in 'social constructivism', which can be conceptualised as 'how the making of social reality can be studied in discourses about certain objects or processes' and critically examining how those discourses in turn influence and shape development pathways, specifically agrivoltaics uptake (Flick, 2012: 450; Kolankiewicz, 2012). To this end, agrivoltaics and decentralised solar installations, as well as perceptions of agrivoltaics, will be examined through its drivers, benefits, risks, and the underlying sociopolitical context and influences. For example, community and farmer perceptions of the agrivoltaics installations will be influenced by how the implementation processes are framed and by whom. Their perceptions will also be influenced by their current feelings surrounding the inevitable change caused by choosing to participate in the energy transition because their capacity to accept and react to change, whether beneficial or detrimental, is influenced by existing systemic sociopolitical structures and relationships.

Critical discourse analysis is an analytical approach that challenges researchers to see words as having 'meaning in a particular historical, social, and political context' (Mogashoa 2014: 104; Johnson & McLean 2020). Further, scholars have applied critical discourse theory to environmental discourses by examining the contentious context the 'environmental debate' is situated within, including how concepts like 'environment' and 'nature' are considered and regulated by policy (Hajer & Versteeg, 2006: 178; Hajer, 2003). Thus, understanding how language is used and what can be inferred, such as what is left unspoken or glossed over, in the specific socio-political and cultural context of my on-location, place-based research will be key. For instance, India's colonial legacies have established the electrification processes in the country, which in turn has implications for renewable energy development, access, and policy (Kale 2014; Lakhanpal 2019). Recognising that all responses exist within this context will be imperative to gaining a more robust understanding of what socio-technical configurations will be the most effective or successful. In addition, what is understood as 'effective' or 'successful' will vary depending on the source and was evaluated as such.

4.4.4. Limitations

While there is the added challenge of applying this analysis method to translated transcripts where I, the researcher, am not familiar with the language of the original transcript, it will still be possible to evaluate the discourses and framings present within these perspectives. With the translated texts, rather than focusing completely on the individual word choice that has been one step removed from the original choice of words through the process of translation, I will focus on the implicit themes, perceptions, and interpretations of my interview questions by the participants. For example, how the participants interpret my questions in the moment is also an indicator of how existing discourses affect perceptions and framings of agrivoltaics and should thus be critically analysed as well.

Interpretation of the discourse with descriptive and interpretive coding will allow room for explanation of why and how the socio-technical configurations are 'constituted, [...] transformed,' and engaged with (Mogashoa, 2014: 106). An example query could include '*how was the community, or farmer, selected to host the agrivoltaics system and what level of communication occurred'*. This will provide insight into accessibility, justice, and community engagement. Finally, combining this approach with other analytical methodologies allows for further interrogation into the use of language, interactions between communities and agrivoltaics, and underlying power relations.

Further, despite the interview transcripts' production within the research setting, the compounded influence of my positionality and worldview, and a translation from Hindi to English, critical discourse analysis will be applied to the interview transcripts as well. It is crucial to understand that while nothing is objective, especially data collected through interviews, this method will provide important insights on the technology, including its development process(es) and corresponding motivations. It will also be vital in examining the differing perceptions of the technology across stakeholder groups.

4.5. Ethical Considerations

There are various ethical considerations that have been considered in the design of this research project. While some of these considerations have been touched upon in previous sections of this chapter, they will be further elaborated here.

There are significant challenges that are affiliated with conducting qualitative field research overseas, and they are multiplied when the said field research is being conducted in a language the researcher is not fluent in. While Hindi and English are the two official languages of India's union government, and English was expected to be used in interviews with experts, politicians, and other researchers, Hindi or the participant's mother tongue[3] was expected to be used in interviews with farmers and community members. Therefore, it was imperative that an interpreter was invited when conducting community interviews. As I was hosted by ICAR-IARI, and visited sites in collaboration with the Institute, another PhD student with experience researching decentralised solar irrigation in India graciously assisted in translating my questions and follow-up questions in the field. While there would have been a worry over the authenticity of the interpretation, including misrepresenting nuances of interview question or the additional complexity associated with my inability to follow along and thus relying on in-the-moment translation from the interpreter, the presence of an interpreter who has some previous knowledge of decentralised solar, albeit not agrivoltaics, ensures that they understand and the context and use the appropriate terminology in the interviews.

There were nevertheless unforeseen complications and ethical considerations associated with conducting interviews in the field and relying on interpretation. Notably, to follow along with the narrative of the interview and thus to have the ability to ask any follow-up questions, the interpreter would translate in the moment while the participants may be speaking in the background. This has resulted in busy, oft-unclear recordings due to multiple voices speaking over each other. While it is

[3] Mother tongue: the term used in India for the other 22 constitutionally recognised, 179 identified, and the approximate 544 dialectal languages (Indian Ministry of Education, 2017).

easier to pick out the English translation, the Hindi is more difficult, even for the interpreter who went back and listened to those sections to parse out any additional information that otherwise would be lost.

In addition, due to the farmers' inability or discomfort with conducting the interviews in English there were challenges with the prepared consent forms as they were in English. While the information sheet and consent form were explained in the field through the interpreter, nuances may have been lost. Thus, verbal and recorded consent adhering to GDPR standards was also sought in the moment. In one case, while it was the intention to only interview one farmer at a time, there were multiple people present, shifting to a more group interview structure, which required amendments to the consent form. There were also other stakeholders present that might have influenced answers due to their presence, including government officials (such as KVK staff, or the ICAR staff accompanying me). As hosts who facilitated the interviews, and out of respect, they could not be asked to step away. In addition, the shift in interview structure in the field during walking interviews to a group interview structure was also ethically considered. Due to resource and time constraints, and in interest of respecting the comfort levels of the participants, I ensured to receive informed consent from each of the participants in the field.

A complication that arose in the field that I did not previously consider involved the presence of research institute and/or KVK staff (re: government officials) during the walking interviews with farmers. Since the farmers interviewed at some sites relied upon KVK programme staff for the initial funding of and trainings for their photovoltaic infrastructure, it was clear in the moment and remarked upon by the interpreter later that the farmer was reluctant to be too critical of the agrivoltaics system in front of the very people who assisted them. Therefore, more critical questions that I hoped to probe more at during these interviews, such as 'Would you choose to do this again if you had the choice?' were discouraged by the knowledge that I would make the participants uncomfortable, which was not my aim. Therefore, questions of this nature were either stricken or rewritten to attempt to broach the subject without any discomfort. For example, the abovementioned question became 'If you could change anything about the system/development/process if you could, would you?'.

When conducting interviews using an interpreter, there are additional ethical considerations related to translation, transcription, and any proofreading I request from a third party. Translation and transcription of the recorded interviews can be accomplished using machine translation, such as Google Translate's audio function, however, required significant editing and proofreading for clarity and accuracy. The PhD candidate at Indian Council for Agricultural Research (ICAR) who acted as interpreter during the field visits, Pratibha Prased, offered to go through the machine translation to proofread for accuracy, thus no other person who was not involved in the data collection process and privy to the responses in the moment has access to the data. While there may have been some concern over the potential for bias in the translation, the development of trust built up between me and Ms Prased acting as a representative for the host institution alleviated any worry that the translation would not be as accurate as possible. The risk mitigation strategy of potentially seeking out a third-party proofreader not affiliated with the institution would establish unbiased data, however there are ethical concerns over handing over the audio files and transcripts to a third party who would then be privy to that information. Therefore, reliant on trust built up between myself and my colleagues at ICAR who also want to ensure robust data, in understanding the risks associated with sharing the data just for another set of eyes, and in the interest of protecting the participants' data, I have opted to forgo the use of a third-party proofreader.

There are also ethical considerations of photography and informed consent that must be fully examined (Richard & Lahman, 2014; Sutton-Brown, 2014). In relation to photo-visual methods, Sutton-Brown (2014) suggests leveraging three different consent forms: the first for the participants before taking any photos, a second acting as an 'acknowledgement and release' for any people that may appear in photos to give permission to be photographed, and the third after the photos are developed, or downloaded, for the participants to give permission for the photos to be used in the research (173). However, this method is very time consuming, and there are options to consolidate, such as using one overarching consent and release form, or focusing mainly on photo-elicitation in interviews. Therefore, photo-elicitation and modified photovoice has been the focus of photo-visual methods for this data collection process. Further, subjective interpretation of the images taken in response to my prompts, similar to photovoice techniques, is more effective in the analysis stage. In other words, the Hindi-English language barrier was a significant limitation when conducting walking interviews in the field with farmers, thus the opportunity to be directed to take photos by the participants removes the intermediary (the interpreter) and allows for me to understand their unique perspective and how they interpreted my question or prompt. For example, an oft-used prompt in the field '*What is the most significant aspect of this system to you?*' can be interpreted in a myriad of ways by the participant, whether by pointing to the benefits the system provides, such as the rainwater harvesting infrastructure, or the aspect of the system they enjoy the most. This technique offers a unique opportunity to view the agrivoltaics system through the participants' eyes and remove the challenge of translation, as well as some of the ethical concern over accurate direct translation, beyond the initial prompting.

Overarching limitations to all data collection methods that must be considered include trust, positionality, and resource constraints. While I was not embedded within a community for an extended period, there was a limit on trust from community members and my accessibility within the community. As a non-Indian, female researcher, it was difficult to build rapport and trust with some groups, and I was unable to speak with certain groups as a result. For example, I was not able to access or hear the lived experiences or perceptions of more marginalised, such as Adivasi (indigenous) people due to my limitations as a foreign researcher. This limitation was mitigated by leveraging NGOs and other community-facing organisations to act as proxies for these communities. Finally, there were time, energy, and resource constraints to my field work.

There are various mitigation methods to address these concerns. Understanding the cultural context of the communities may mitigate the risk of access. Leveraging connections with academics and experts within and outside India helped ameliorate access, and even trust, concerns depending on the situation. Although, it was important to be mindful of the positionality of these contacts as well and how they might impact data collection. Furthermore, where appropriate, leveraging online resources, including Whatsapp and document databases, and online or remote interviews for certain stakeholders, such as developers, academics, and/or central government officials assisted in mitigating time and resource constraints.

4.6. Conclusion

The methodologies discussed in this chapter highlight the interdisciplinary nature of agrivoltaics research, specifically when taking a qualitative approach. The utilisation of document analysis provides important context for the current state of decentralised solar and agrivoltaics policy in India while also presenting the different stakeholder framings of the technologies. The utilisation of semi-structured interviews allows for flexible discussions with various stakeholders and contribute to the development of an overarching narrative of agrivoltaics implementation in India. Further, the combination photo-visual techniques with the interviews provides another dimension to the narrative, including situational context as well as improving interviewee participation and subsequent inclusion of their perspectives in the data. The combination of these methodologies is conducive to the development of a robust research product that meaningfully contributes to the growing body of literature on agrivoltaics, which will be discussed in the following results and discussion chapters.

Chapter 5: Presenting Agrivoltaics: Framing Stakeholder Perceptions and Evaluating the Existence of an Enabling Environment

5.1. Introduction

Agrivoltaics is a relatively new technology with the potential to transform the energy and agricultural sectors. However, due to its relative nascency, there is limited research examining the long-term impacts of agrivoltaics development and alternative configurations within the context of emerging economies. There is a growing collection of policy regulating agrivoltaics by ensuring agricultural land and cultivation protection with solar energy generation (Worringham, 2021). However, in India, where research is limited to demonstration and pilot installations, there is limited regulation and no specific policy guidelines that include agrivoltaics.

Despite this, the national PM-KUSUM Scheme directed at promoting decentralised solar and boosting electrification gives a passing mention to dual-use solar energy. The scheme itself is framed as a vehicle for 'farmer welfare' (Government of India, 2019a: 2), however, its implementation indicates that it is little more than an empty signifier. A long history of dispossession for the sake of development, first in the colonial era and continuing today regarding renewable energies under a Hindu-nationalist government, indicates that the only currently existing policy to reference agrivoltaics does not provide a suitable enabling environment and thus has the potential to perpetuate this history.

The central aim of this thesis is to address an existing gap in agrivoltaics research analysing stakeholder and farmer perceptions based on lived experiences, specifically in decentralised contexts in emerging economies. To this end, an analytical framework that integrates social acceptance, disruptive innovation, and energy justice perspectives is applied to evaluate stakeholder perceptions of the emergence of agrivoltaics in India, along with the on the ground realities of farmers actively engaged with decentralised solar and agrivoltaics systems in northwestern India. To this end, this chapter addresses the varying frames utilised by various stakeholders that influence acceptability and justice outcomes. First, I will analyse the enabling environment for agrivoltaics through examining existing policy frameworks and key decision-makers' and other stakeholders' perceptions. Following this evaluation, the impact on acceptability and adoption outcomes will be discussed.

The concept of 'frames' are understood to constitute a variety of perspectives that have 'implications [on] multiple values and considerations', such as in this case, acceptability and acceptance of agrivoltaics (Chong & Druckman, 2007: 104). As a process, 'framing' assists in developing a specific 'conceptualisation of an issue or reorient' a certain way of thinking (Chong & Druckman, 2007: 104). Alternatively, as a tool commonly used in marketing and policymaking, stakeholders, such as developers, often consciously use language to develop frames to 'position their organisation and its policy preferences to greatest effect' and encourage other stakeholders, such as key decision-makers, to share their perspectives (McGrath, 2007: 269). Accordingly, frames and the framing process are subjective lenses that can be applied to a concept or intervention that have the potential to influence social acceptability.

As an example, Torma and Aschermann-Witzel (2024) developed personas to discuss, localise, and frame agrivoltaics in broad contexts as a method of gauging hypothetical acceptability. As agrivoltaics adoption increases, it is imperative that frames and perceptions of the technology is examined accordingly. Both the documentation analysed, and elite and community-facing organisation stakeholders interviewed, present agrivoltaics in unique ways, understanding how these frames influence perceptions and social acceptability in an Indian context as a crucial first step for this research. Thus, before developing an analysis of the social acceptability of agrivoltaics in India, the different frames utilised will first be unpacked and analysed in this chapter.

Through the examination of the PM-KUSUM Scheme (hereafter the Scheme) and Indian policy documents, this chapter will analyse how the framing and introduction of agrivoltaics is misleading, at risk of perpetuating past harms, limits the potential for an enabling environment for implementation, and thus represents an empty signifier. The creation of an enabling environment is dependent upon context but can be identified by the broad themes of market and policy reforms; investment in support infrastructure and public services; and transparent governance with the intention to improve community capacities (Meyer & Neethling, 2017; Meyer & Meyer, 2016; Kuyvenhoven, 2004). An empty signifier is generally applied to broad, often polysemous concepts like sustainability (Brown, 2016) or corruption (Huss, 2018) to address the 'possibility of signifying the limits' of 'signification' with the 'limit' indicating what has been 'excluded from discourse' (Brown, 2016: 117-118). Essentially, this process involves identifying what has been overlooked in the discourse and giving name to it, even if this identified concept does not cause real-world impact. For example, lending significance to a phrase like 'sustainable development' does not indicate that a sustainable process will follow. Additional policies and regulations must follow to realise the impact of this term. By doing so, this designation of empty signifier recognises the outside influences that shape the discursive frames of that concept or process. For instance, the concept of empty signifier has also been applied to infrastructure and development processes as a method of recognising and examining the colonial and neoliberal socio-political influences on those development processes (Kirshner & Baptista, 2023). In the context of this project, the historical dispossession and exploitation of rural farmers from the colonial period to today under the Hindu nationalist central government influence not only how the Scheme is presented as a method of addressing past societal harms but also how the Scheme is implemented.

I begin by examining the notion of marginal and unproductive lands in India. I then turn to the framing and presentation of the Scheme in this context. Through the analysis of policy and research documentation and interview results, this chapter will discuss the existence, or non-existence, of an enabling environment of agrivoltaics in India based on the current socio-political landscape. Ultimately, I put forth the argument that the Scheme has attempted to facilitate farmer welfare through accessible opportunities for rural electrification, however, it has faltered through implementation, which renders the Scheme ineffective in meeting its objectives for the intended beneficiaries.

5.2. Marginal Farmers and 'Unproductive Land'

A political construct, marginal[4] lands are classified as such to 'indicate "empty", "unproductive" land "available"' for development (Baka, 2014: 315). This designation is not specific to India; rather it is a term utilised in a range of contexts, including in regions of resources extraction (Dunlap, 2017; Goldberg, 2023; O'Sullivan et al., 2020; Stock & Birkenholtz, 2021). However, the designation has been used by developers, both national and local governments, and other regulatory bodies and decision-makers in India to support 'problematic land politics' that allow for the 'unmaking of space for capital accumulation' such as renewable energy systems (Singh, 2022: 402). Despite the framing of the Scheme as one that fosters farmers' welfare, the use of 'wasteland' designations negates that framing. Phrases such as 'giving [farmers] an opportunity to increase their income by utilising their barren and uncultivable land for solar' (Government of India 2019a: 2) suggests many of India's farmers are not considered as meeting their full, productive potential. This echoes existing perspectives adopted and popularised by developers and governmental agencies in the US that justify the development of solar on unproductive agricultural land as a method of 'keeping the family farm' (Goldberg, 2023: 3). Strategies framing solar development as a farmland preservation tool have the potential to improve social acceptability of the technology, however there is little evidence that suggests how the developments will affect 'soil health and future farm viability' (Goldberg: 2023: 3). In this way, government stakeholders are acknowledged as framing solar, including agrivoltaics, as pro-environment and pro-farmer without a clear understanding of the long-term implications, such as yet-unknown impacts on land, soil, and ecosystem services. In India, there is less consideration for positive framings, with instead a history of 'hugely controversial dispossession-driven projects in infrastructure, real estate, industry, mining, and solar energy' (Silva et al., 2020: 1302).

[4] The majority of farmers in India are classed as 'marginal farmers', which is estimated by various interview participants as making up anywhere between 70-90% of farmers (GOI Employee, 2023; NGO 1, 2023). 'Marginal' is a Reserve Bank of India classification of farmers that hold one hectare of land or less. Smallholder farmers, for reference, hold between one and two hectares (Government of India, 2019b). The term 'marginal' is understood as a classification among farmers, and they do not generally feel marginalised by the use of this classification—it is simply a land ownership designation.

Considering India's legacy as an 'epicentre' of global 'green land grabs' and subsequent protests (Levien, 2018: 2, 221), the Scheme's emergence as a possible vehicle for restorative justice, in this case recognising, addressing, and providing opportunities for mitigating historical exclusion from energy access, security, and development. However, as evidenced above, the Scheme may present a just policy intervention, but it is noted to 'falter' at the implementation stage (National Researcher, 2023). The Scheme promotes the installation of solar energy infrastructure on agricultural land to boost renewable energy production and considers participation in the Scheme as a reasonable use of 'uncultivable' or underutilised space (Government of India, 2019a: 2). Nevertheless, the Scheme does not consider how rural farmers might already use their land despite its 'unproductive' or 'barren' designation.

Historically, traditional pastoral and cattle grazing practices have first been identified as 'primitive' and even blamed for environmental degradation during the colonial era, and then consistently 're-allocated' for alternative but 'useful' purposes, including 'afforestation and industrialisation programmes' (Singh, 2022: 407). Dispossessive and state-sanctioned land grabs were common occurrences during the colonial period and were acts that 'catered to corporate investments' and provided too little, if any, compensation or rehabilitation to the displaced small farmers or indigenous groups (Silva et al, 2020: 2-3; Levien, 2018). Current instances of land grabs for renewable energy developments, including hydroelectric, wind, and commercial solar, are reminiscent of this history of marginalisation that has contributed to a physical loss of generational land as well as a sense of lost identities for small and pastoral farmers (Singh, 2022). Notably, several interview participants, including one agrivoltaics developer (AVS Developer) and an NGO Director (NGO 3) have argued that this process is recurring through the introduction of renewable energy programmes such as the Scheme (AVS Developer, 2024; NGO 3, 2024).

Technological interventions for climate mitigation define what qualifies as development and how that development can be achieved through an exercise of power and control that privileges elite stakeholder perspectives (Baka, 2017; Singh, 2022). In India, there is a 'distant relationship' between the decision-maker, the manufacturer, and the user—in this case, the farmer—that impacts the eventual effect of an intervention like solar or agrivoltaics (NGO 3, 2024). Disconnected processes such as these reinforce how the power of discourse, framing, and presentations create meaning and influence shared beliefs of renewable energy systems as ones that underutilised lands must accommodate. In other words, the disconnect between stakeholders at various levels is contributing to an established norm of both solar and agrivoltaics implementation strategies that favour large-scale developments and commercial viability over communal benefits under the pretence of making the 'right' call (Glover et al., 2019: 171). The acceptance of such configurations perpetuates the colonial and neocolonial understandings that land deemed unproductive is of little value and should be transformed accordingly. This justifies further land dispossession for the sake of the renewable energy transition in 'solar extractivist' processes that favour corporate interests and detrimentally impacts social acceptability at the community-level (Hu, 2023: 2). This emphasises the importance of recognising injustices within policymaking and implementation, specifically regarding emerging technologies like agrivoltaics, and ameliorating those impacts. Only through doing so might an enabling environment for just agrivoltaics be produced.

However, the overarching macro-level (or the national policy level) acceptance of this extractivist nature of development legitimise these processes and establish them as the incumbent method of implementation from which future developments will emulate. Thus, the use of language such as 'barren' or 'uncultivable' in policy documentation that positions itself as one that facilitates farmer welfare reinforces the notion that renewables are the best option for development regardless of risks for further marginalisation.

Already, this legacy dispossession has influenced perceptions of renewable energy policies, including the Scheme. Both the vague phrasing related to compensation if farmers lease their lands to solar developers and unclear financial structures, as well as existing knowledge of corruption has influenced perceptions of it:

> Everyone wants them [subsidies] but the needy don't get them. [Someone else] can produce a document and forge this thing […] the subsidies are not really adopted, really the money is just taken without implementation. […] So, they [farmers] think that there is a lot of corruption there (NGO 2, 2023).

> You understand that there are dynamics of the land. [Honestly], it's like the land mafia control all these internal arrangements of land and everything. So, it's mostly driven by politicians who are really having a strong hold in that district (AVS Developer, 2024).

It is evident that non-farming, non-elite stakeholders understand the complicated relationship farmers have with the central government during renewable energy installation processes. Thus, there are concerns that existing biases or trust deficits for national institutions would reduce acceptability of a new technological innovation. A technology framed and promoted as facilitating 'farmer welfare' may be perceived as misleading due to awareness of intentions to '[ecologically] modernise' land into more 'valuable' renewable energy generation facilities (Stock et al., 2023: 5).

In addition, the introduction of agrivoltaics is both confusing and only briefly mentioned with little clarification. In the Scheme documentation, 'cultivable land' may also be used for solar provided that the panels are on stilts 'where crops can be grown below […] and sell RE power to the Discoms' (Government of India, 2019a: 2). Recent concerns regarding greenwashing solar energy by developers, decisionmakers, and scholars to uplift the national profile have grown (Hu, 2023). Further, the lack of specific regulations may contribute to this emerging concern within agrivoltaics development discussions. In a context wherein Indian farmers and rural communities have been marginalised by renewable energy developments in the past under a guise of supporting and meeting climate goals (Kale & Sovacool, 2019), the negligible introduction of agrivoltaics may contribute to a reluctance to accept, support, or adopt it. Furthermore, this insubstantial inclusion in a policy document that frames itself as a vehicle for farmer welfare while faltering at the implementation stage will only negatively impact agrivoltaics acceptability. The Scheme itself may act as an empty signifier that promotes a proposed reality as one that facilitates decentralised solar development, however its specificity related to grid connectivity and ignorance of agrivoltaics' off-grid potential indicates the frame and presentation of the policy is markedly different from reality.

Renewable energy will play a significant role in the ongoing and future mitigation of climate change, and offer opportunities decentralised renewables may provide for vulnerable and peripheralized communities. Thus, this argument is not intended to disparage the role of solar and agrivoltaics, however it is important to recognise that renewable energy infrastructure and justice do not always overlap (Wallsgrove et al., 2022; Hazrati et al., 2021). As exemplified by both India's history and present, renewable energy installations may result in dispossession, exploitation, and other injustices that must be considered to address and hopefully restore these harms in future developments.

The above observations suggest the importance of evaluating new policies and legislation to understand how a policy intervention is being presented to then examine the resulting on the ground realities and implications. For instance, the introduction of the Scheme guidelines in documentation indicate that the policy can only be effective for farmers that are fortunate enough to already be or could afford to be connected to the local grid supplied and managed by local sub-stations (Government of India, 2019a). This caveat is significant because of the central government's struggles achieving rural electrification (Kale, 2014). This caveat's use, that only solar systems located 'near these sub-stations' present opportunities for additional income, ultimately justifies the high upfront costs of installation, but disqualifies any farmer who is neither grid-connected nor has the capacity to afford a connection (Government of India, 2019a). Even if a farmer is grid-connected, the unreliable distribution infrastructure in need of upgrades remains beyond their capabilities. In this context, only large-scale agrivoltaics developments either installed by large landowners or commercial interests will be implemented because they have a higher likelihood of grid connectivity, capacity to upgrade the local grid to accommodate the installation, and encourage land acquisition through potentially government sanctioned, dispossessive means. Thus, many small or marginal farmers, who would benefit most from the Scheme and agrivoltaics' holistic benefits, are disqualified from participation.

This interpretation is significant because it relates back to calls for improved distributive, recognitional, and procedural energy justice processes within renewable energy policy development and implementation. It is evident that this Scheme has overlooked or disregarded these processes and has thus produced a solar policy that is ineffective or inaccessible to many farmers. This argument will be further elaborated on in the following sections of this chapter. Further, the discussed misconceptions of the Scheme will continue in the following section, however this background on and context for marginal farmers was introduced to contextualise the following discussion and analysis.

5.3. Solar Policy Misconceptions and Empty Signifiers: The PM-KUSUM Scheme

5.3.1. Definitions, Terminology, and Practical Realities

Agrivoltaics first appeared in Indian policy documentation as part of the revised PM-KUSUM[5] Scheme (translated by the Government of India from the Hindi as the Prime Minister's Farmers Energy Security and Upliftment Campaign) that promotes decentralised solar installations on a '[farmer's] own land' (Government of India, 2024: 2). The type of land or crop cultivation is not specified by the official documentation but is consistently referred to as land owned by 'one or more farmers' (Government of India, 2019a). This policy focuses primarily on solar-powered groundwater irrigation pumps; however, Component A of the policy allows for the development of solar installation on what is termed 'uncultivable' land:

> 'Cultivable land may also be used if the solar plants are set up on stilts where crops can be grown below the stilts and sell RE power to DISCOMs [regional and local electricity distribution companies] (Government of India 2019a: 2).

While allowance for dual-use installations is briefly noted, the policy documentation stipulates that such a system is installed on stilts with enough clearance for agricultural machinery to pass underneath (Government of India 2019a). This clarification echoes definitions in existing agrivoltaics policy in other countries, such as France and Germany, and suggests that a solar system must meet these stringent requirements to be considered agrivoltaics (Worringham, 2021). Explicitly stated requirements in policy are recognised as a method of protecting agricultural land from landowners prioritising energy production, however it does disallow flexibility for potential adopters at smaller scales who do not use machinery or may not require as large a land commitment (Worringham, 2021; Mahto et al., 2021). While minimal, within the Indian context where the average farmer is classified as small or marginal, this contextual distinction indicates the difference between technological adoption or inability to adopt, otherwise known as rejection (Busse & Siebert, 2019). As will be elaborated below (in Chapters 6 and 7), an allowance for flexibility in conceptualisation and configuration improves further social acceptability and inspires further technological innovation of agrivoltaics systems at decentralised scales.

[5] In Hindi: Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan

Component B of the Scheme includes the planned installation of 17.5 lakh[6] (equivalent to 1.75 million) standalone solar irrigation pumps up to 7.5 horsepower, with solar panel kilowattage of corresponding amount, in this case a maximum of 7.5 kW. Component C involves the planned solarisation of 10 lakh (equivalent to 1 million) grid-connected, pre-existing solar irrigation pumps of up to 7.5 horsepower (Government of India 2019a). Component B was fully introduced with immediate effect in 2019, whereas Components A and C were introduced in 2019 first as pilot programmes with plans to scale up as necessary. The Government aims to facilitate 25,750 MW of new solar in the country via this Scheme (Government of India 2019a). This aim was slated to be met between 2019 and 2022, however with the COVID-19 pandemic, the Scheme end-date has been extended annually (Government of India, 2020; 2021; 2022).

While Component C has been argued by government and elite stakeholders interviewed for this study as having potential for the inclusion of agrivoltaics through the sustainable integration of solar panels to 'solarise' existing irrigation pumps (National Researcher 2023; GOI Employee, 2023), this possibility is not mentioned in the analysed documentation and is dependent on allowances for experimentation by farmers. Thus, this possibility, among other pathways of adaptation and innovation, will be discussed in Chapter 7. However, analysis in this chapter will focus predominately on Component A as the most directly aligned with agrivoltaics.

The Scheme was initially introduced by the Ministry of New and Renewable Energy (MNRE) in 2014 as a method of promoting decentralised solar and ensuring energy security for farmers, in addition contributing toward the nation's renewable energy goal of 40% by 2030 (Government of India 2024). According to one government interview participant, the initial aim was to encourage 'youth[s] and farmers' to participate in the solar programmes (GOI Employee 2023). This perspective is reiterated in secondary sources pertaining to solar policy and the Scheme, including news articles and reports published by research institutions (Rahman, 2023). Most recently, a 2024 report recommending 'agri-solar best practices' presents the Scheme as a transformative opportunity for farmers to engage in the innovative approach (Pulipaka et al., 2024). The central objectives of the Scheme as introduced in the documentation include: decarbonisation of the agricultural sector, reducing fossil fuel dependency, and saving costs for farmers; providing water and energy security for farmers to ensure reliable 'irrigation and energy supply'; increasing farmers' incomes by 'enabling' them to sell surplus energy to the grid and earn additional income; reducing environmental pollution and greenhouse gas emissions while enhancing soil health; and generating potential for 'direct employment among rural communities' (Pulipaka et al., 2024: 15). Theorised to minimise environmental and land pressures and provide

[6] Terminology local to Indian policy documents and conversation, such as lakh and horsepower, will be utilised in this section with clarifications. The purpose of this choice is to use the phrasing used by the documents as well as many of the participants in this project and indigenise the research (see Chapter 4: Methodology and Methods for more detail on this choice).

resource security, agrivoltaics have the potential to address these aims (Gomez-Casanovas et al., 2023). Thus, the Scheme is presented as an opportunity for rural and small farmers to improve energy and freshwater access through Components B and C, and potentially also improve financial security through Component A. On the surface, the Scheme is designed to mitigate past harms resulting from a history of exploitation and dispossession from large-scale infrastructural developments and Green Revolution interventions (Khara & Ghuman, 2023). However, the aims of the Scheme are potentially difficult to realise in practice due to this exclusionary legacy as well as misrepresentation of what is attainable for the average Indian farmer.

While the central government frames the solar transition through a lens of farmer welfare in the official documentation, the evident dichotomy between the presentation of the policy and its implementation in practise indicates an overarching aim focused on achieving national electrification and renewable energy goals, over holistic resource security at the community level. An analyst based at a national research institute explained the superficial inclusion of agrivoltaics in this policy:

> PM-KUSUM is the first scheme to mention agrivoltaics in any of the policies. But […] it gives a passing mention to agrivoltaics, saying if its cultivable land, farmers have to set up the whole solar power plant on a stilt so that they can continue growing crops. And it's not a lot [not very specific]. I mean, it's just saying that we *can* support this, but does the scheme have any…targeted method for improving the agrivoltaic? I don't think so (National Researcher, 2023, emphasis added).

This analyst is critical of the inclusion of agrivoltaics within the Scheme because it is unclear what purpose its inclusion has and for whom it was intended for. Such a 'passing mention' of agrivoltaics generates only confusion as limited information on what the technology is, including its benefits and implications, has been provided in the documentation. Perhaps its inclusion is to act as an introduction of agrivoltaics, however 'farmers aren't aware that this kind of thing [technology] is available' (GOI Employee, 2023) and are no better informed from the Scheme. Thus, this policy informs developers and others within the private sector, rather than the agricultural sector.

The Scheme was introduced by the MNRE to reduce over-exploitation of energy and water resources by farmers, echoing the resource security frames communicated in the documentation. To reduce over-exploitation without the Scheme, one participant argued, meters would need to be installed that tracks resource usage, but 'convincing the power companies [Discoms] to install a meter is a big task' (GOI Employee, 2023). With knowledge of both the Discoms' existing energy and subsidy 'burdens', the central government 'intentionally' did not include subsidies in Component A, the Component that identifies agrivoltaics as a possibility, of the Scheme (GOI Employee, 2023). Instead, ‘we wanted [the Component] to stand on its own as a commercial instrument rather than something that is heavily subsidised by the government’ (GOI Employee, 2023).

This participant frames programme participation as one that should be achieved through self-funding, rather than the subsidies that many farmers would expect to receive. For example, as one participant highlighted, farmer participation in the scheme was ‘conditional’ on the existence of subsidisation (KVK Delhi, 2023). However, whether because solar is no longer considered a niche energy system and a more accepted renewable energy intervention (Kirshner et al., 2019b), is now considered over-subsidised for its popularity, or due to the nascency of agrivoltaics as a yet-unaccepted technology, government subsidisation ‘doesn’t make sense at this point of implementation of renewable energy [programmes] in the country’ (GOI Employee, 2023). A central government representative speaking on their involvement in the development of this Scheme, indicating that renewable energy programmes, specifically for ones involving decentralised solar energy, do not require a subsidy ‘at this point’ emphasises a general understanding that government assistance should be phased out. While it is unclear whether this is since the central government believes solar is too widespread, has been over-subsidised, or a combination of the two, this statement provides a basis for the economic frame taken by the documents and this participant. Regardless of the exact context of such a statement, the general understanding at the national level appears to be one that no longer believes it needs, wants, or plans to provide large subsidies for solar development, let alone agrivoltaics. This lack of available subsidisation may reduce overall acceptability of decentralised solar technologies due to its large, often unattainable upfront cost, but it will also further reduce the ability for smallholder, marginal, and rural farmers from installing it. Thus, for a Scheme promoting farmer welfare through solar installation, it is evident that the reality is significantly different. Instead of engendering rural, decentralised solar development resulting in reliable access to renewable energy that may also generate additional income for a household, the combination of no subsidy, grid-proximity limits, and potential infrastructure updates in the Scheme renders such promises of farmer welfare meaningless (AVS Developer, 2024).

In comparison, European research institutions present agrivoltaics as a vehicle for bolstering energy security while promoting economic and land use efficiency and conservation (Trommsdorff et al., 2022). India’s central government takes a similar approach by emphasising energy insecurity in the Scheme documentation. The documents utilise phrases such as Discoms ‘are not in a position to energise these [existing irrigation] pumps through grid connection’ and solarisation can reduce ‘their burden’ supplying and subsidising electricity to a high-consuming agricultural sector (Government of India 2019a: 2). In practice, Discoms view solar as ‘competition’ (AVS Developer, 2024). Despite initial intentions and commitments by the central government to make electricity available to all Indians following Independence in 1947, the ‘initial conduit’ of rural electrification was via agriculture and irrigation via experimentation with devolved, privately, and publicly owned utilities post-independence (Kale, 2014: 4). This pathway had broad public support but ultimately had the unintended consequences of eroding grid stability over time and 'exacerbating inequality between rural citizens' due to limited oversight and disjointed regulation (Kale, 2014: 4).

The complicated regulatory structure resulting from this ownership mix across states has resulted in fragmented electrification and regulation over time, perpetuating existing wealth and resource security gaps between states, villages, and even households. Despite increased incidence of national electrification campaigns and central government reports touting the success of these campaigns, scholars note that electricity access remains largely unchanged (Blankenship et al., 2020). Where grid connectivity has been improved, reliability of infrastructure quality and electricity access remain significant issues (AVS Developer, 2024; AVS 2, 2024). A further example of the reality of this disparity is illustrated in my observations in the field of a clear difference in infrastructural maintenance, technical support for broken solar, irrigation, and other agricultural equipment, and electricity access between the Delhi greenbelt, an agricultural preservation area surrounding the national capital, and the state of Haryana, underscoring the difference in regulation across state lines (field notes, 2023).

As a result of extant energy accessibility and reliability issues, present-day Discoms' capabilities not only differ between states with conflicting decentralised regulations, but also as whole remain 'burdened' by the agricultural industry's energy usage as well as increased energy needs in general (Government of India 2019a: 2). In this context, the central government frames the Scheme as a method of addressing this burden on Discoms and prevalent energy insecurity through decentralised solarisation. However, despite this approach, Discoms have been noted as being less than accepting of solar energy in general (AVS Developer, 2024; Singh, 2022). One developer interviewee emphasised that Discoms 'hate solar in India', see solar energy as a 'threat' to their revenue streams reliant on household tariffs, and only promote it 'out of compulsion or regulatory mandate' by the government (AVS Developer, 2024). Thus, it is evident that improved top-down support for community-level solar infrastructure and accessibility will be required to encourage support within distribution companies (Joshi & Yenneti, 2020). Such top-down approaches must also work in conjunction with community-level participatory approaches to encourage social acceptability of the policy and technology. While this condition for social acceptance will be further elaborated on in Chapter 6, however its cruciality is important to note here to contextualise the gap in support for solar at multiple regulatory levels.

Arguably, the central government has framed the Scheme as a mitigating factor for the widely acknowledged lack of support for solar from Discoms, by emphasising an easy transition both for the utilities and potential adopters. By attempting to improve the Discoms' perceptions of the technology by framing it as a method of reducing resource insecurity and electricity load, national stakeholders may be attempting to encourage solar uptake. However, if Discoms do not wish to be 'unburdened' by solar and thus have their revenue streams impacted, the utilities possess the capacity to hinder solar uptake through the rejection of applications for solar or prioritising other forms of development, such as housing (AVS Developer, 2024). Solar may not impact revenues if feed-in tariff opportunities were more readily available, however unreliable grid infrastructure, stipulations that farmers may be tasked with upgrading the transmission infrastructure, combined with some Discoms posing limits for feed-in reduce this potential (AVS Developer, 2024; AVS 1, 2023). It then becomes prohibitive for farmers to consider grid-connected solar, move forward with off-grid installations, and continue to contribute to the Discoms' arguments regarding 'competition'.

Discoms are even further disincentivised to encourage agrivoltaics developments not least because of the lack of central government mandate or quota, but because of the potential adverse impacts to their revenues through the proliferation of solar. Discoms are important stakeholders in the solar industry because of their ability to promote implementation campaigns and facilitate solar development through coordination with developers and provision of grid connectivity, if needed. However, despite the potential for the opening of a new market, or revenue streams through the sale of electricity generated from grid-connected solar systems, Discoms remain unwilling to support the industry (AVS Developer, 2024).

Additionally, despite electricity's place as a quintessential pillar of development (Kale, 2014), and improved access to electricity pointing to improved welfare for rural citizens (Bhandari et al., 2018), the Scheme disregards another crucial factor: the Indian farming community's capacity to realistically participate. The majority of India's farmers are classified as small or marginal farmers, which is indicative of correspondingly small land ownership, or lack thereof, and limited financial capacity to upgrade their agricultural practices, such as through solar. While the Scheme is presented as a vehicle for participation in the solar transition for the 'little guys' (GOI Employee, 2023), its strict regulations requiring infrastructural upgrades, upfront cost, and energy production quotas disincentivise participation from small-scale farmers uninterested in the risk. In addition to these concerns of miscommunication regarding the Scheme, there are also conflicting frames, financing information, and land ownership.

5.3.2. The Limits of Financing, Infrastructure, and Land Ownership

The solar installations through the Scheme's Component A are 'preferably' to be installed 'within [a] five km radius [from] the [Discom] substation' to reduce transmission costs and losses (Government of India 2019a: 2). This requirement indicates that participation is dependent on geographic proximity to the grid, and that such proximity results in benefits for the farmers. Specifically taking an economic benefit lens in analysing the Scheme's Component A, farmers would be able to supplement their income through the sale of electricity to the grid, to be paid out by the Discom over the 25-year lease lifetime of the installation as stipulated in the MNRE-approved Power Purchase Agreements (Government of India, 2019a). This is similar to existing feed-in tariff policies in other countries, however Discoms may also be given a Procurement Based Incentive (PBI) for each unit (kW) purchased or per MW of solar installed over the first five years (Government of India, 2019a). Despite this attempt at incentivisation for Discoms, it has had limited effect (AVS Developer, 2024).

Nevertheless, the inclusion of specific geographic proximity to the grid within this Component is indicative of the fact that localising agrivoltaics policy to an Indian context is 'not being recognised at the top level' (National Researcher, 2023). Rather, the use of the word 'preferably' in documentation denotes an aspect of flexibility in spatial proximity limits, yet it does not negate the reality that farmers can only supplement their income under this Component if they are already grid-connected or have the financial capacity to improve infrastructure themselves to be grid-connected. Under Component A, the solar system:

> may be connected to a substation, but the RPG [Renewable Power Generator, e.g. the farmer, farmer collective, or other nature of installer] will be responsible for laying the dedicated […] line

from the installation to the substation, including all necessary grid and metering infrastructure and upgrades (Government of India 2019a: 5). This highlights the stipulation that the owner of the solar systems, the RPG, must cover the cost of either installing or upgrading transmission and distribution infrastructure themselves, which is likely beyond the capacity of many farmers (NGO 2, 2023).

Further, in the case that farmers do not possess the purchasing power to install solar on their own, they may opt for developers or their local Discom to install solar with the farmers receiving land rent based on Rupees (Rs) per year per acre or Rs per unit of energy generated per acre (Government of India 2019a). Farmers who have opted for developers or their local Discom to install solar are in this case no longer the RPG (renewable power generator) and are thus not responsible for the cost of installation and any required upgrades but only receive rent costs and the receipt of solar energy produced on their land is up to the discretion of the RPG. While this fact does not appear in the Scheme text nor in the secondary literature, the absence of specifying what happens to the electricity produced by a third party-owned system illustrates a disconnect between policy documentation and practical realities.

In an environment that has historically bypassed farmers for energy services provision, from intentional exclusion in the colonial period to corruption and mismanagement from local Discoms today (Kale, 2014; Stock & Sovacool, 2023), it cannot be guaranteed that the energy produced on a farmer's land will be accessible to them. In other words, the farmers who have leased their land for solar development are neither guaranteed specific compensation from the developer nor ability to use the electricity that is produced on their land. This oversight in the Scheme's language reduces potential for increasing farmer ownership as many lack the purchasing power to install solar on their own. Instead, the Component engenders third party ownership by those with potentially limited knowledge of local agricultural best practices and the impact of solar infrastructure on its surrounding environment, as well as fostering fears of land competition and exploitation (AVS Developer, 2024). While decentralised solar ownership models and microgrids offer alternatives for farmers to exert agency over their land (Joshi & Yenneti, 2020; Dutta, 2020), implementing agrivoltaics under this Scheme remains prohibitive for most Indian farmers without significant financial capital.

Even when farmers showed interest in the technology, the cost of installing an unsubsidised technology–estimated by the Government Employee (2023) participant to be approximately 4.5 to 5 crore rupees (or half a million GBP) per megawatt–is significantly prohibitive for many farmers in India. While this cost estimation was slightly overinflated by the interviewee, and despite the increasing relative affordability of solar panels compared to just a decade ago (Mulvaney 2017, Gomez-Casanovas et al., 2023; Horowitz et al., 2020), the cost to install solar remains prohibitive to many without 'reasonable, safe' from exploitation financial support mechanisms (AVS 2, 2024). In addition, the published estimates globally for the cost of solar per megawatt may be becoming more affordable, however these estimates do not consider the additional materials needed for agrivoltaics that significantly increase the price. For example, to account for these additional materials and 'site investigation costs' agrivoltaics systems are estimated to have an 'installed cost premium' of $0.07 to 0.80 USD per watt over traditional ground-mounted solar, a cost that can quickly accumulate (Horowitz et al., 2020: 19). In fact, it is common for small and marginal farmers to be further marginalised by solar development in India rather than reaping its benefits (Stock & Birkenholtz, 2021). This is largely due to the focus on large-scale solar developments by the central government and further prioritised by a policy like the Scheme that prevents participation by small-scale farmers through the utilisation of unclear language and restrictive impact.

Component A of this Scheme does not provide an upfront subsidy for solar development, however, provides resources to loan financing schemes (Government of India, 2020). Despite this, there remain notable equity issues as only farmers with larger incomes and stable credit can participate in such financing schemes. Even if a farmer receives a loan to install solar, they will be expected to provide some of the cost regardless:

> So, [with] loan financing, any project is loan financed and even the loan finance project you need to give some upfront contribution from the beneficiary side, which is 30% [under the Scheme] which is again in millions. So that is simply not possible. [...] If all farmers are coming in to do this, it is already well-off large farmers [progressive farmers] who can finance this (National Researcher, 2023).

The central government's focus on a scheme like PM-KUSUM was to encourage small and medium-scale farmers to participate and 'reap the benefits [...] rather than the big guys' (or large-scale solar developments) taking all the benefits (GOI Employee, 2023). So, it was deemed crucial that the government encouraged the support of banks across the country, and establishing a national subsidy price, to varying degrees of success (GOI Employee, 2023). With the cost of participation so exorbitant, the only way to encourage small and medium-scale farmers, of whom many would be categorised as 'marginal farmers,' to potentially risk their livelihoods is the assurance of financial support and safety nets. In practice, the Scheme is not as effective as planned, with the Scheme acting as a barrier for solar development in general while also perceived to be 'throttling' agrivoltaics development potential:

> [The Scheme] effectively acts as a barrier for agrivoltaics rather than promoting it. The reason is agrivoltaics in the context that I mentioned, may be beneficial in some areas, like arid areas, and peri-urban areas, where the land is there. But when you put a uniform tariff across the state or country, what happens is you are [prohibiting people due to costs]. So, if you are a developer who wants to set up agrivoltaics, you don't have to set up a plant in these areas, you can go set it up in some remote places […] So, it's effectively, by announcing a uniform tariff across the states [regardless of capacity, both financial and land], it is effectively sort of throttling agrivoltaics (National Researcher, 2023).

> Even you can do some of those possible like in the centralised policy but comes to be the interventions application that's going to be state subject where the decentralised institute is going to be pragmatic rather than, okay, one policy across the country that will not work in India. We have 29 states, and each state has its own agriculture [sector to consider] (NGO 2, 2023).

In terms of understanding the Scheme, by implementing a uniform, national subsidy price, the central government essentially prohibits small-scale farmers from participating in the scheme due to the diminished returns available to them. A large-scale farmer with excess land and income may be more inclined to participate in the Scheme as the subsidy is not only substantial but due to their ability to install a larger number of solar panels, they may witness a faster and bigger return on investment (Trommsdorf et al., 2022). In contrast, a small or marginal farmer who has only one acre, less, or does not own land at all will be less inclined to participate as a 70% subsidy remains out of reach because they cannot match the not-any-less-substantial 30% that is left (NGO 1, 2023). In addition, they would not be able to install the same number of panels a large-scale farmer would be able to, thus not seeing the same amount of financial return. To small and marginal farmers, a national, uniform tariff is not considered an option for them. This insight links back to concerns over accessibility, specifically regarding distributional and recognitional justice. The accessibility or lack thereof of a policy renders a scheme like this out of reach, dismissive of a significant farmer demographic's capacity to participate, and ultimately unconcerned with large-scale uptake of the technology. As evidenced by previous renewable energy developments installed at the expense of community well-being (Singh, 2022; Lakhanpal, 2019), a disregard for just processes that recognise a demographic's ability to engage, whether through infrastructure accessibility or financial support, only contributes to negative perceptions of a policy and the technology it promotes, reducing its social acceptability.

In terms of solar infrastructure available to farmers, the Scheme documentation also emphasises that multiple checks for installation 'quality' control mechanisms will be undertaken, including only opening bidding process to developers of solar pumps or 'controllers or manufacturers of solar panels' (Government of India, 2019a: 10). This stipulation is aimed at ensuring not only that the system installed is of good quality, but also that 'post-installation services' will be provided (Government of India, 2019a: 10). Safeguards such as these are expected to generate trust in government policy (Alexandre et al., 2018), and participants have indicated a greater degree of trust in the central government as a result, especially when compared with developers and Discoms (GOI Employee, 2023; NGO 1, 2023). However, an industry perspective points to instances where the Scheme reneges on such guarantees (AVS Developer, 2024). In practice, Scheme installations have been recognised as of 'cheap, substandard quality' with farmers given limited maintenance support from developers and Discoms (AVS Developer, 2024). Thus, the solar systems' materials are decaying at a much faster rate and expected to last 5 to 10 years rather than the promised 25 (AVS Developer, 2024).

Arguably, the importance of financial capacity to improve infrastructure if not already grid-connected and to afford the upfront costs of an elevated agrivoltaics system built using high-quality materials indicate that Component A, and thus existing agrivoltaics development policy, is aimed primarily at larger landowners with established wealth and capacity to install it (AVS Developer, 2024). Despite the Scheme's overarching frame as a vehicle for farmer welfare, marginal and smallholder farmers ultimately do not have the capacity to participate in the Scheme, nor compete with larger landowning farmers who will attract loans and developers:

> On the National level, we are looking to catch up with the targets of solar green energy. So, the government is actually looking at [it] as a farmer welfare scheme. [But] When I say welfare, this is not actually government's money, but actually some commercial entity bringing in some money for the benefit of farmers, which are actually larger landowners (AVS Developer, 2024).

Ultimately, the financial requirements for agrivoltaics implementation in India requires significant investment not only in materials but support infrastructure as well. As this quote emphasises, farmer welfare may be the promoted objective of the Scheme, but without governmental financial support mechanisms, only large landowning farmers supported by commercial industries and interests can do so. This generates a supportive culture for large-scale agrivoltaics that is exclusionary to the average farmer and engenders opportunities for 'solar extractivist' practices at the expense of smaller-scale farmers (Hu, 2023). This would also potentially contribute to a negative understanding of the technology within those excluded groups, as dispossessive development practices have been identified as detrimentally impacting social acceptability of renewable energy (Singh, 2023; Hu, 2020).

According to one industry developer, for instance, landowners with accumulated savings have in many cases opted to install solar under this Scheme as an investment for the lease period, hire agricultural labourers to farm, and have indicated plans to remove the solar after the lease concludes and sell their land to industrial developers as the land prices are expected to increase (AVS Developer, 2024). While this example applies specifically to this developer's experience in Delhi, agricultural landowners more broadly tend to see solar as a mechanism for compounding income and an intermittent phase before selling the land altogether. Further, 'political elements', such as regulatory bodies or decision-makers favouring one applicant over another due to political influence or even bribery, may play a role as the Scheme is suggested to be funded by commercial and industrial interests (AVS Developer, 2024). Such influence is not unheard of in India as local government officials may be convinced to sway decision-making on land leases and renewable energy configurations (Singh, 2022; AVS Developer, 2024). If this is the case, it would both be difficult to document such conflict of interests and to evidence that this conflict of interests encourages solar industry developers to prioritise wealthier landowners over other groups. Thus, it might be argued that developers who fund this Scheme have encouraged the use of the framing of farmer welfare for numerous reasons. One of these may include for the purposes of fostering a positive public image, while facilitating solar development only for landowners who already have the capacity to participate. A central government Scheme that promotes itself as generating farmer welfare on the international stage (Pulipaka et al., 2022; 2024) cannot produce holistic welfare across the agricultural community if it systematically excludes certain demographics in practice.

As exemplified by the 2020-2021 farmer protests in northwestern India, attempts to favour commercial agriculture over the average farmer or agricultural worker has resulted in policy change and recognition of the collective power of India's farmers (Kumar, 2021; Lerche, 2021). Arguably, if farmers continue to be disincentivised to participate in the Scheme due to the financial issues discussed above, future acceptability of solar and agrivoltaics may be detrimentally impacted. However, due to limited access to information and miscommunication about the Scheme itself, it may be just as likely that social awareness is simply not at a stage as to encourage large-scale rejection of the policy. Nevertheless, appreciation for the collective power of farmers to overturn unfavourable policy for the wider agricultural community is necessary. Thus, the following section will discuss the misrepresentation of information and its implications on potential adoption outcomes.

5.3.3. Knowledge Gaps and Miscommunications

While issues pertaining to financing and land ownership indicate a disingenuous policy frame that prioritises large-scale developments over systems at the small and medium-scale, existing gaps in knowledge due to limited access to accurate information and miscommunication further illustrate the Scheme's functioning as an empty signifier.

As noted, the Scheme does include a subsidy of at least 30% but as much as 70% (NGO 1 2023; SP1 2023; KVK Haryana 2023) on solar irrigation pump installation (Components B and C) in line with industry standard for technology interventions in India. Agrivoltaics (Component A) does not fall under this subsidisation. However, agrivoltaics development would not fall under this subsidy as it 'doesn't make sense at this point [...] of implementation of renewable energy [programmes] in the country' (GOI Employee, 2023). While it is the 'general notion' that the Scheme would include 'direct monetary contribution' for the farmers, the Government 'wanted [the Scheme] to stand on its own' as a 'commercial instrument' (GOI Employee, 2023).

The motivation behind this new financing scheme was to circumvent the 'conventional' method of renewable energy development in India and for the Scheme to 'stand on its own' as perhaps to establish itself as a model for a new pathway to energy development in India, it has not had its desired effect (GOI Employee, 2023). While various policy reports published both independently and through the central government suggest potential business models for the Scheme and agrivoltaics more generally, none of these models consider agrivoltaics configurations disconnected from grid infrastructure (Government of India, 2024; Pulipaka et al., 2024; Rahman, 2023). Each of these business models assume that the farmer would receive financial benefits from the sale of energy to the grid yet given India's uneven energy infrastructure and gaps in energy access (Kale, 2014), many rural communities would not be able to reap such benefits. Furthermore, the assumption that rural communities might be able to reap these benefits, as indicated by the Scheme documentation, will likely impact the eventual acceptability of the technology. If these benefits are not realised, agrivoltaics as a nascent technology could be rejected, rather than socially accepted because it does not meet the expectations of the farming community.

The reduction in subsidies for a new technology can be interpreted in multiple ways: low confidence in agrivoltaics by policymakers, the belief that solar is widespread enough and considered part of the energy sector regime that subsidies are no longer necessary to encourage uptake (Kirshner, et al., 2019), or the intention to focus on commercial-scale developments that do not require heavy subsidisation from the outset. Despite notable scepticism of agrivoltaics' role in India's agricultural industry among national stakeholders, including impracticality for small-scale developments (National Researcher, 2023) and the unaffordability of the materials (NGO 2, 2023), these criticisms do not necessarily point to an overarching low confidence within the central government itself. On the contrary, the establishment of multiple pilot projects to investigate configurations feasible for agrivoltaics scale-up within the Indian context reflects a growing interest in the technology's future (Pulipaka, et.al., 2023). However, this may indicate an interest in research to inform larger installations instead of encouraging development of diverse and scalable configurations. Further, if the assumption is that solar is widespread enough and that commercial-scale developments are the goal, the central government may observe financial subsidies as unnecessary and move to cut them.

Ultimately, the fact that decentralised agrivoltaics have not been considered in this Scheme may be indicative of the decreasing prioritisation of decentralised solar developments by the central government, which may be more interested in meeting its renewable energy goals of 500 gigawatts (GW) by 2030 through large-scale developments, with 488 GW attributed to solar energy (Government of India, 2024; Stock and Sovacool, 2023). Or this oversight could simply be due to the limited understanding of the implications of a novel technology, or socio-technical niche. As a central government stakeholder has indicated, farmers 'aren't aware' of such innovative technologies despite informational campaigns (GOI Employee, 2023). This lack of awareness, paired with unclear policy deviating from the status quo of financial incentivisation, does impact access to the technology and consequently, social perceptions and acceptability of agrivoltaics in India. Without proper knowledge dissemination and engagement with the farming community as an equal stakeholder in the decision-making process, a major component of the policy's audience may remain sceptical of the technology, if they are even made aware of it at all.

According to one participant from a rural capacity building nongovernmental organisation, farmers generally see solar as 'free energy' or a 'free asset' (NGO 3, 2024). The central government may have limited the subsidies available to curtail this mindset among farmers and reduce advantage-taking, however this new business model instead may generate more negative perceptions among the farmers. To the farming community, solar is expected to always come with subsidies (NGO 3, 2024; GOI Employee, 2023), and a lack thereof would arguably detrimentally impact social acceptability at the community scale.

Farmers may come to expect—but also depend on—subsidies to assist with the upfront costs of interventions and will continue to do so as solar is scaled-up in India (NGO 2, 2023). The fact that receiving subsidies has become a 'trend', and that farmers are considered to 'take advantage' of receiving a maximum subsidy to the point that they 'no longer depend on farming' may have contributed to the vague language utilised in the Scheme, especially in Component A (KVK Haryana, 2023). Essentially, while some farmers may benefit from installing solar at minimal cost, there are implications associated with framing solar solely through an economic lens. There is a risk of increasing focus on energy generation rather than agricultural cultivation, often with noted instances of farmers leaving solar-powered irrigation pumps open constantly because the energy is 'free' (SP 1, 2023), thus contributing to overexploitation of water resources in often water-stressed regions (KVK Haryana 2023; NGO 1, 2023) and producing further environmental harms. While some stakeholders who work closely with farming communities emphasise that 'total' subsidisation is 'not good for them [farmers]' because of the lack of care they might have for the system and its impacts (KVK Haryana, 2023), participants nevertheless recognise that for agrivoltaics to be promoted, accepted, and adopted 'then farmers will need it [subsidies]' (KVK Delhi 2023).

When examining India's energy sector, understanding the dynamics between specific communities, from grid-connected urban neighbourhoods to decentralised rural villages, and the energy systems in place is crucial. Since the Green Revolution, which commenced in 1966—and continues in a scaled-back but nonetheless present capacity today through research conducted by ICAR—to combat food insecurity by developing, dissemination, and incentivising high-yield crops (Khara & Ghuman, 2023; Yamauchi, 2007), the farming community has historically received financial incentives and support from both the central and regional governments to aid in sectoral transitions (GOI Employee, 2023). This expectation is now applied to the solarisation of agriculture in India and therefore, the divergence from this well-established model of providing financial subsidy by the central or regional government in a highly publicised scheme like PM-KUSUM is risking negative perceptions of the Scheme itself, but also agrivoltaics and decentralised solar by association. While it is evident that a combination of top-down and grassroots approaches will be required to compromise on the nature of subsidies while increasing farmer accessibility (Joshi & Yenneti, 2020), removing subsidies because of concerns of farmers' advantage-taking without introducing a replacement financial support structure only further exacerbates inaccessibility and distributional injustices.

Further, while renewable energy policy documents are generally full of technical and legal jargon indecipherable to many, understandable policy, in contrast, would reduce the risk of exploitation of vulnerable groups with limited experience engaging with such policy. The central government had announced that all national documentation will be produced in both English and Hindi to make policy more accessible (Government of India, 2021). Yet, even translating the policy into Hindi does not automatically render it more accessible, as indicated by the confusion acknowledged by experts (NGO 3, 2024; GOI Employee, 2023). Indeed, the publication of policy documents in Hindi and English disregards the existence of the hundreds of other mother tongues[7] throughout the sub-continent, including other widely spoken languages such as Urdu. Thus, this renders this complex financial scheme inaccessible by those who lacked formal education or fluency in these two languages, as many are in states with different state-recognised languages, or in Adivasi or tribal communities. Scholarship on the relationship between solar energy development and communities indicates a clear pattern of community dispossession in India (Singh, 2022; Dutta, 2021). Scholars argue that the existing neoliberal political structures reinforce colonial racial capitalism by deliberately prioritising large-scale solar developments

[7] 'Mother tongues' is the phrase used throughout India to reference native language, which can include Hindi or English, but is usually applied to one of the other hundreds of languages used throughout India. In the interest of adhering to my intention to 'indigenise' my results and not overwrite existing Indian English terminology with a more Western term—an act that can be construed as inherently colonial—I have kept the phrase 'mother tongues' here.

owned by Indian and international elites while marginalising rural, marginalised communities, specifically those of non-Hindu ethnicity or lower financial capacity (Stock and Sovacool, 2023; Sultana, 2022). In the context of the Scheme and understanding that the majority of farmers are classed as 'marginal[8] farmers' who may only use their mother tongue confidently—estimated by various interviewees (GOI Employee, 2023; National Researcher, 2023; NGO 1, 2023) throughout this project to be anywhere from 70-90% of farmers—cultivating in rural and disconnected areas, it is evident that such policy decisions deliberately exclude certain demographics.

Early interactions with farmers highlighted the concern over inaccessibility of information of the Scheme, and confusion over Component A, as farmers were noted to express interest only to discover the Scheme is not what they thought it to be (GOI Employee, 2023; National Researcher, 2023). Specifically, the lack of financial incentive was emphasised as a central concern:

> Why would farmers adopt [an] agrivoltaics system? Is there any incentive for them to adopt it? No, that incentive mechanism is completely missing (NGO 2, 2023).

National stakeholders recognised that growing 'confusion and misunderstanding […] would bring rather negative sentiments' about the Scheme and sought to combat this growing scepticism (GOI Employee, 2023). These efforts included attempts at clarification through eleven subsequent memos over four years (Government of India, 2019a: 2020: 2021: 2022), community engagement, and awareness campaigns. The government participant recognised that inaccessibility to accurate information and general confusion regarding the Scheme would influence farmers' perceptions of the policy as well as the technology. However, despite efforts to include or centre farmer perspectives prior to the Scheme's launch, that did not come to fruition in the way they hoped. The scale of necessary stakeholder workshops with farmers was an immense and challenging undertaking that 'would have thrown the whole process into an unending discussion spree' and thus was not conducted to representational scale (GOI Employee, 2023).

This lack of diversity of perspectives in community engagement processes has resulted in a Scheme that is both technically dense and neglectful of the average farmer's ability to participate. While cataloguing farmer perspectives across the sub-continent would have been a challenging undertaking, the choice to limit community-level engagement further illustrates the Scheme's role as an empty signifier.

> Regarding the equity part of it, I'm again pessimistic because I don't see the people who are in charge [the central government] understanding. So, in several meetings, or you know,

[8] 'Marginal' is a Reserve Bank of India classification of farmers that hold 1 hectare of land or less. Smallholder farmers, for reference, hold more than 1 hectare but less than 2 hectares (GOI 2019). The term 'marginal' is understood as a classification among farmers, and is considered different to 'marginalised', although there is likely significant overlap. This term will be discussed at more length in following chapters.

workshops, I raised this question again and again. So, you are talking about agrivoltaics. What is the value you are seeking to bring out of it? Is it that you want farmers to increase their income, or are you worried about land, etc.? [...] But I don't see that kind of, you know, engagement that is needed (National Researcher, 2023).

This participant emphasises that even in workshops during the Scheme's development phase, the eventual goal of the inclusion of agrivoltaics was unclear. The negligible inclusion of agrivoltaics within Component A reflects both a limited understanding of agrivoltaics developments, including best practices, lived experiences, and implications in the long-term, as well as an effort to spotlight innovative configurations at different scales and energy capacity and contribution to national climate goals.

The inclusion of agrivoltaics in this Scheme can be understood as misleading at best, and deliberately deceptive at worst to increase the profile of the Scheme as progressive without contributing to agrivoltaics development in any meaningful way or aligned with justice procedures. The limited information available and the extant misconceptions have not been addressed at time of writing and have consequently prevented the wider farming community from participating in agrivoltaics uptake (AVS 2, 2024). These factors indicate that the inclusion of agrivoltaics within this Scheme was not intended to foster development. This begs the question as to what purpose, and for whom, its inclusion was for. If the technology is promoted and included in national policy but does not come with regulations, consideration of context and diverse farmer capabilities, and a roadmap for implementation, then it is simply not accessible for those whom it might be intended. This may be due to the limited research available on the impact of agrivoltaics in India, however it may also be due to the disinterest in adapting the incumbent understanding of the technology to the Indian context, not only on the central government's part but within the research community's as well. Despite the contributors' best intentions, the Scheme's positioning as a vehicle for farmer welfare is ultimately misleading. Undoubtedly, certain demographics of farmers, notably large- and commercial-scale farmers, will experience benefits from this programme and from agrivoltaics in general. However, limited distribution infrastructure dependent on upgrades, recognised substandard quality of materials, unsupportive energy distribution companies (discoms) who view solar in general as a 'threat', and the prioritisation of wealthier landowners over marginal farmers who may see the greatest difference in terms of resource security combine to indicate that the Scheme promotes false promises. In other words, the Scheme may prove to be an empty signifier, an inherently political gesture that does not meet the needs or expectation of its supposed objectives and prevents the promotion of an enabling environment (Swyngedouw 2011).

5.4. The Disabling Environment of India's Agrivoltaics Policy

An enabling environment for development interventions is inherently dependent on context, however scholars have identified broad themes that contribute to its creation, including trade, market, and policy reforms; investment in public services and support infrastructure; and transparent governance with intention to empower communities (Meyer & Neethling, 2017; Meyer & Meyer, 2016). Within the context of the global agriculture sector, sustained exploitation of the farming community has adversely affected development processes within those communities (Kuyvenhoven, 2004). Sustained exploitation of the marginal agricultural communities in India through uneven electricity infrastructure and dispossessive renewable energy installations has contributed to stalled development within many rural communities (Kale, 2014). The combination of this dispossession, the implementation of a decentralised solar policy that misrepresents its feasible outcomes, and the insubstantial introduction of agrivoltaics within that ineffectual policy ultimately reflects a lack of an enabling environment for agrivoltaics scale-out and widespread acceptance.

Significantly, the Scheme prevents participation for many farmers who are systematically excluded from participation for reasons such as arbitrary distance from grid infrastructure, financial capabilities, and land ownership. External barriers including limited specific regulation offering both transparency and protections for potential adopters of agrivoltaics, as well as a lack of financial incentive or subsidisation that would encourage acceptability and accessibility for the average farmer also exist. Instead of an enabling atmosphere, the Scheme produces an exclusionary environment for the average Indian farmer and, as a result, implicates agrivoltaics as another prohibitive technology.

The dichotomy of the sole Indian policy that includes agrivoltaics, however minor, presenting the technology as a vehicle for farmer welfare with how it might realistically work in practice is stark. As has been discussed, the current iteration of the Scheme is more prohibitive and exclusionary than national stakeholder participants might have hoped (GOI Employee, 2023). While regulatory support for a technology lends legitimacy to potential adopters (Cousse, 2021), the misleading framing of the Scheme is expected to generate confusion and distrust over the policy's implementation processes and consequently, influence acceptability outcomes of the technology itself (National Researcher, 2023; Wallsgrove et al., 2022). Participation in the Scheme is dependent on grid proximity, infrastructure accessibility, and financial capacity, as well as capability to understand the Scheme's use of at times inaccessible language. Thus, it is identified as currently 'just a policy' that is accessible only to 'well-off, large farmers who can finance this', while effectively excluding the average farmer and contributing to a decrease in legitimacy among that demographic (National Researcher, 2023). Ultimately, these factors contribute to negative perceptions of agrivoltaics among the average farmer community, if they are aware of the technology and its corresponding references in policy, at all.

Financial barriers as a direct result of limited to no subsidisation or support represent the overarching concerns for widespread agrivoltaics scale-out in India, however issues with miscommunication, knowledge accessibility, and a history of land competition and exploitation from energy developments also influence willingness, or unwillingness, to accept agrivoltaics. The central government's efforts to facilitate national and rural electrification are notable and a challenging undertaking in a diverse climatic, geographical, and socio-linguistic country. However, policies promoting resource security built upon compounding concerns of confusing or misleading financing guidelines and risk protections, hidden costs, and deficient infrastructure may result in further distrust among potentially vulnerable farming communities. Ultimately, trust in institutions is lacking in India because there are limited opportunities for 'bi-directional learning' (Goyal & Howlett, 2020: 517; Singh, 2022). This eventually results in stagnating innovation aimed at preserving financial outcomes and reducing risk, which will require a degree of flexibility to encourage further uptake of agrivoltaics among the majority agricultural community (Joshi & Yenneti, 2020; Jacobssen & Bergek, 2011). However, current policies that are propositioned to achieve accessibility and energy security for decentralised solar energy, agrivoltaics' inclusion remains prohibitive to many farmers because the implementation strategies follow exclusionary and potentially dispossessive incumbent methods of doing so. Strategies are needed to respond to this growing distrust among farmers for national policies, counteract these incumbent strategies, and facilitate experimentation among the agricultural community to stimulate alternative adaptive and accessible solar installations.

Thus, through its misleading promises and the underlying influences of historic exclusionary practises, the Scheme represents an empty signifier, or a significant policy lacking 'real' significance. In other words, due to its overall inaccessibility for the average Indian farmer, the intended broad impact of the Scheme is instead limited. Further, the identification of the disconnect between the Scheme's original intentions—addressing rural electrification through the proliferation of decentralised solar or the possibility of dual-use installations on agricultural land to encourage farmer welfare—with the limited feasibility of adoption by the average farmer, also illustrates the false promise of agrivoltaics scale-out through this Scheme. In this case, the Scheme proposes and is presented as a restorative mitigating solution to historical injustices that excluded and continue to exclude small, marginal, and decentralised farmers from development processes. However, through its introduction in Component A, the Scheme continues to perpetuate these injustices because of its inaccessibility to the average farmer (Dutt, 2020; Levien et al., 2021). Without an enabling environment for the equitable introduction of agrivoltaics, the technology will not be accessible or useful to those who could benefit most from it (Kumar, 2024).

The average farmer, identified as small or marginal, in comparison to the large or progressive farmer, may not have 'much motivation' because of the lack of support they require to participate in an energy transition (NGO 1, 2023). While energy justice is often employed as an evaluative lens on existing energy installations to determine its socio-economic implications, it can also be used as a predictive rather than reactive 'transformative tool' to contribute to addressing 'wider systemic injustices' (Wallsgrove et al., 2022: 148). In this context, restorative energy justice processes can be deployed to empower previously excluded communities to address and mitigate past harms, including historic land dispossession and impediments to participation in transition policy (Hazrati et al., 2021). However, as exemplified by the Scheme, not all efforts at restoration are effective. A central criticism of restorative justice practices is that such practices are focused on 'private conduct and private resolutions' even when applied to broader public injustices, such as rural electrification and solarisation (Wallsgrove et al., 2022: 148; Zehr, 2015). The Scheme is presented as a vehicle for farmer welfare through solarisation, however the prioritisation of large-scale solar installations in its applicability emphasises a focus on corporate (such as private distribution companies and developers) interests and bolstering the national solar profile, over small-scale, grassroots benefits that agrivoltaics might potentially provide (Gomez-Casanovas et al., 2023). The Scheme's inaccessibility to the average farmer reiterates the requirement for policy development that addresses existing inequalities in the energy transition and generates an enabling environment that considers not only private interest, but also public investment requirements, community needs and perspective, and contribution from all stakeholder levels, including those at the grassroots level (Joshi & Yenneti, 2020).

For the Scheme and Components B and C specifically, while there is financial support through subsidies, there remains a preference for geographical proximity to the grid and a developer perspective of inadequate, substandard materials used for these subsidised installations (AVS Developer, 2024). Component A also requires geographical proximity to grid infrastructure. However, because it also lacks financial support through the policy itself, participation in this Scheme and subsequently the agrivoltaics transition is dependent on private support, which is not considered economically viable for many developers (AVS Developer, 2024).

The requirement for private financial support, whether through leasing land to developers or acquiring potentially predatory loans (NGO 2, 2023), to engage with Component A reflects the notion that the Scheme is not offering restorative justice. The current conceptualisation of agrivoltaics in India, as introduced through the Scheme, is one of a technology that has the potential to improve land efficiency and climate resilience, but also one that is only accessible to those who can afford it. However, to achieve a transformative or just transition that includes agrivoltaics, there must be greater consideration for capacity building and farmer self-determination regarding involvement (Wallsgrove et al., 2022). As has been exemplified, the lack of consideration for farmer participation and agency in policymaking and design has contributed to policy that remains exclusionary and falters during implementation processes (National Researcher, 2023). This disconnect between the intentions behind the Scheme and the reality of its implementation highlights how the perpetuation of neoliberal, exclusionary renewable energy policies in India influences how agrivoltaics are being introduced. In turn, this reality affects how agrivoltaics are being accepted or rejected, and by whom. Ultimately, this creation of an enabling environment only for those who can afford it illegitimises agrivoltaics for many potential users because it is not considered as 'for them'. A disabling environment for agrivoltaics will continue, regardless of the climate resilience co-benefits available to farmers at different scales, if opportunities for flexibility, or *jugaad*, to develop an agrivoltaics that can 'better fit' these contexts can flourish.

While the Scheme's contributors' ambitious intentions for rural electrification are notable, the scale of stakeholder workshop and knowledge co-development was beyond the scope of the capacity provided to them. Further, existing practices of policy design contributed to a Scheme that perpetuates an incumbent business model that often prioritises large-scale developments and wealthier landowners. The Scheme's positioning and promotion as a vehicle for farmer welfare or resource security only prevents opportunities for farmers unused to parsing technical documents. It may also result in disappointment and rejection of agrivoltaics by other vulnerable yet interested groups, potentially influencing further non-adoption, or even perpetuate existing experiences of marginalisation and exploitation.

The concerns of farmers because of this misleading presentation of decentralised solar and agrivoltaics will be further elaborated on in the following chapter. Not only will barriers be examined from the perspective of decentralised solar pump and agrivoltaics farmers, but so will the drivers that encouraged their solar installations. Finally, opportunities for encouraging future development through an examination of the conditions that would need to be met will conclude the chapter.

Chapter 6: Conditional Acceptability of Agrivoltaics: Barriers, Risks, and Opportunities that Influence Adoption

6.1. Introduction

Acceptability is understood as the willingness to adopt a technology or innovation (Alexandre et al., 2018; Cousse, 2021). It can be distinguished from social acceptance, often used as an overarching term to include acceptability pre-adoption, but it also involves evaluating acceptance and corresponding social perceptions of a technology post-adoption (Busse & Siebert, 2018). As was discussed in Chapter 3, acceptability is a subjective process that is dependent on context and availability of knowledge exchange, dissemination, and co-production (Hai, 2019). In other words, social acceptance is reliant upon a specific stakeholder or potential adopter having a robust understanding of a technology based on accurate and accessible information. For instance, the observed disconnect between policy intention and implementation in India, combined with a lack of suitable enabling environments for agrivoltaics, point to a generalised political or national level rather than community level acceptance.

Analysis of key documents suggests that India's central government is interested in promoting agrivoltaics, which indicates a degree of acceptance within the political sphere. However, this macro-level acceptance does not equate micro-level, or the community or individual level, acceptance (Upham et al., 2015). Rather, in India's case, the lack of an enabling environment might include factors such as gaps in reliable grid infrastructure and supportive financing opportunities, which contribute to a corresponding lack of community and individual acceptance. Understanding social acceptance of an emerging technology or innovation is crucial for understanding and predicting the eventual longevity of the technology because, regardless of its merits, if communities do not support it, the technology will not last.

India is an emerging leader in agrivoltaics development in Asia and globally, with a growing body of pilot research facilities and increasing interest in further developments (Pulipaka et al., 2023). The current body of existing agrivoltaics research internationally is focused on North American and European case studies, with some exceptions and growing global focus. Despite this shift, most policy and regulations specific to agrivoltaics exist in predominately Global North countries (Barron-Gafford et al., 2019; Schindele, 2021a; Tajima & Iida, 2021). The regulations implemented in these countries, out of necessity, have introduced specific regulations designed to ensure that neither agriculture nor energy production are detrimentally affected through the incorporation of a dual-use practice. As such, these policies have influenced agrivoltaics conceptualisations and configurations in these countries as well as in other settings, including India (Worringham, 2021). Despite India's emergence as a leader in agrivoltaics research, the introduction of the technology thus far is reminiscent of the incumbent norm of agrivoltaics definitions that may not be best suited to India's majority medium, small, and marginal-scale agriculture industry. In addition, India has not yet introduced a specific agrivoltaics policy, thus leaving its introduction to the market. Without specific regulations, however, there is a noted risk for unjust and exploitative processes reminiscent of existing dispossessive commercial renewable energy installations in India (Singh, 2022). Regardless of growing interest in agrivoltaics among farmers, knowledge and experience of exploitative and misleading energy policy have the potential to detrimentally influence the perceptions, and adoption outcomes of the technology (Dutt, 2020). Thus, it will be imperative to understand the perceptions of agrivoltaics from stakeholders and farmers to evaluate the future potential of the technology.

Chapter 5 compared how agrivoltaics are framed in national policy documentation and the critiques of the frames from various stakeholders. It also established the Scheme as unconducive for the establishment of an enabling environment for agrivoltaics. This chapter will build upon this examination to critically analyse how stakeholder perceptions have been impacted by this disconnect. It will also discuss how social acceptance and perceptions of solar, including agrivoltaics, are influenced by these perceptions. To this end, this chapter will draw from social acceptance and energy justice frameworks to evaluate the perceptions of agrivoltaics pre- and post-adoption, identify the drivers, barriers, and risks to entry, and consider the conditions that may improve acceptability and adoption in this specific context.

First, results gleaned from stakeholder and farmer interviews will be introduced and evaluated through the employment of social acceptance and energy justice literature. Second, this discussion will be followed by an examination of how the noted drivers, barriers, and risks, in conjunction with an unsupportive regulatory landscape, influence perceptions of the participants. This will enable the exploration of how the disconnect between policy and implementation, noted above, has come to influence acceptability of agrivoltaics systems. The chapter will conclude by considering that although farming and community stakeholders have noted explicit conditions that shape their acceptance, they remain optimistic about the future of the technology in India. As such, there are significant opportunities that would engender more inclusive and sustainable agrivoltaics implementation in India given that farmer perceptions are considered.

6.2. Evaluating Drivers, Barriers, and Risks of Agrivoltaics Adoption

To evaluate the drivers, barriers, and risks of agrivoltaics implementation in India, this section will categorise and address them according to an overarching theme. Since many of these factors are linked, it is notable that each driver for participation has a corresponding risk associated with it. For instance, farmers are driven by the prospect of financial security agrivoltaics are theorised to provide, however, the high upfront cost to installing agrivoltaics is a barrier to entry and carries a significant risk to their livelihood and wellbeing should they invest and potentially not reap the financial benefits they were promised. Thus, in this section, these perceptions of agrivoltaics will be discussed through a comprehensive thematic framework, starting with financial opportunities and challenges, continuing with uneven development and energy security, and finally, knowledge accessibility and exchange.

6.2.1. Financial Opportunities and Land Conflict Challenges

The most noted driver of adoption by participants is the potential economic security solar energy provides, whether through cost savings from generating their own electricity or through the premise of selling excess electricity produced back to the grid through feed-in tariff and other grid connection mechanisms (AVS 1, 2023; SP 2, 2023, NGO 2, 2023).

Agriculture may be the 'backbone' of India's economy, but on a smaller scale, it is also the source of many farmers' sole income (NGO 1, 2023). Unpredictable cultivation and crop production results in increases of financial instability and has a direct correlation to the rise in farmer suicides in India (Mariappan & Zhou, 2019; Patnayak, 2023). Thus, the combination of resource security from the existence of solar energy that provides reliable access to groundwater to irrigate land during periods of extreme heat, increasing drought, and irregular rainfall, as well as with the ability to sell any excess electricity back to the grid for supplemental, reliable income is recognised as a significant driver for agrivoltaics adoption in India (AVS 2, 2024).

During one site visit inside the Delhi Greenbelt, a one-kilometre-wide protected agricultural belt surrounding Delhi, early adopting farmers were clear on their motivation to install agrivoltaics (AVS 1, 2023). Using a modified photovoice methodology when directed to capture an image of the most important aspect of the agrivoltaics system, one of the farmers wanted the solar panels to be the clear focus (see Image 1). To him, and to the other farmers at the site, the solar panels were the most important part of the system because they provided a 'double benefit' of a dual-use system (AVS 1, 2023). Not only do the farmers know that their crops are protected, but because 'electricity is being generated on top', it can be sold for additional income (AVS 1, 2023). As seen in Image 1, the solar panels are placed close together without allowing for much sunlight to reach the crops. From their identification of the close solar panel configuration as the most significant aspect, it is evident that the farmers prioritised electricity generation and financial opportunities when opting to install the system. However, three years post-adoption, the farmers now recognise the slight 'damage' to their agricultural beds and crop production due to reduced sunlight (AVS 1, 2023).

[Image 1: Agrivoltaics installation with turmeric and banana, located at AVS 1 site (Authors' Own, 2023)]

The four farmers in this case were approached by solar developers to consolidate their single acres and lease their total combined land for the installation. They received assistance from their local Krishi Vigyan Kendra (one of a network of partially government-funded farmer capacity building institutions) when designing and implementing their system. In this installation scenario, the farmers receive land rent from developers for the use of their land for the standard 25-year lease period given to most solar energy developments (GOI Employee, 2023; KVK Delhi 2023). They also benefit from a grid-connection that allows for additional income through feed-in tariffs and were assured that the farmers would be able to continue to cultivate. While the developers also opted to encourage the farmers' opinions in the design process, there was limited accurate information regarding agrivoltaics' impacts on agricultural land available to them to ensure that the farmers were making an informed decision (AVS 1, 2023). Essentially, the farmers in this case were not aware of the potential damaging effects closely configured solar panels could have on their agricultural productivity, ultimately contributing to their current perception of agrivoltaics as a technology that 'encroaches' on their land (AVS 1, 2023). Ultimately, despite efforts to involve the farmers within the decision-making and design process, the limited information available on suitable configurations and lack of confidence regarding 'what questions to ask' (NGO 3, 2023), the agrivoltaics installation is not as effective. Thus, the importance of 'bi-directional learning' and participatory partnerships between stakeholders is crucial because, as this case illustrates, not one stakeholder group has full authority over a multi-disciplinary technology's (agrivoltaics) implementation best practices (Goyal & Howlett, 2020: 316; Glover et al., 2019). Rather, a farmer will understand how to integrate the system into their crop production and a developer will leverage their knowledge to design an appropriate installation. Thus, this case represents the importance of knowledge exchange within the agrivoltaics transition, not least because of its emerging nature, limited practical research, and the need for a more robust knowledge base.

Similar to concerns with land competition, another farmer in the neighbouring state of Haryana has had a solar-powered irrigation pump (solar pump) on his land for a 'few' years (SP 1, 2023). When prompted to consider the possibility of transitioning to an agrivoltaics system, this participant highlighted that he and other farmers might feel that their 'land [will] be encroached upon' if they were to install it (SP 1, 2023). It is understood that this perception of encroachment might influence social acceptability of the technology and potentially reduce adoption outcomes, especially as farmer-to-farmer communication and opinions are highly valued and acknowledged (Mahto et al., 2021). However, it could be argued that commitments to bi-directional learning and improved accessibility to information outlining opportunities, risks, and best practices may contribute to ameliorating fears over land competition.

Despite the Delhi agrivoltaics farmers' concerns over land encroachment to the implications for agricultural production, they expressed they still would have opted to install the system. Before the installation, the farmers could not sustain their livelihoods on agriculture alone, and had to take on additional, less desirable manual labour, including contributing to funerary services (AVS 1, 2023). Now, with the additional energy and financial security the agrivoltaics system provides through lease rent and the sale of excess electricity to the grid, the Delhi farmers no longer must seek additional work beyond agriculture. Thus, despite the negative impacts observed to their crops, the farmers are secure in their choice even to install agrivoltaics. When asked if there was an aspect they would like to change if they could, one of the farmers expressed an interest in transparent panels so they could improve their cultivation while maintaining the same, or more, energy production (AVS 1, 2023). Regardless of concerns for land encroachment and reduced agricultural productivity, this case emphasises that economic benefits are a central motivating factor for agrivoltaics acceptability among Indian farmers.

While the Delhi Agrivoltaics farmers' experience indicates that opportunities for improved financial security outweigh the potential implications for agricultural production, many other rural and decentralised farmers do not have the same ability to install agrivoltaics. As noted in Chapter 5, the Scheme provides substantial financial subsidies for solar irrigation pumps in Components B and C of the policy. However, Component A, the section of the Scheme that applies to and includes agrivoltaics if not in name than in reference, does not provide any financial assistance for installation. Thus, any farmer that is interested in installing agrivoltaics on their land must either possess the upfront capital or capacity to do so, which excludes many farmers in India (NGO 2, 2023). Community stakeholders indicate that anywhere between 70 and 90% of farmers are classified as small- and marginal-scale (NGO 1, 2023; NGO 3, 2024), and their capacity to integrate the technology is minimal:

> Their land area is less than [..] 0.5 hectares. […] To be honest, they are among the most economically deprived. So, their annual income is barely enough to support their daily [needs]. Now, if we bring in Agrivoltaics, are they going to benefit? First of all, the cost of setting up a [solar] power plant runs into millions of rupees. And that is even beyond the lifetime of their [marginal farmers] income. So, there is no chance that a typical farmer will be able to finance the whole thing (National Researcher, 2023).

Despite this acknowledgement of the average farmers' capabilities, the current business models for agrivoltaics in India are entirely dependent on large landowning farmers. The National Researcher (2023) participant presented various business models agrivoltaics implementation could follow but expressed that an approach that allows for the 'market to take the lead' would be the most effective. Since agrivoltaics are currently the most cost-effective the larger in scale they are, this approach would only encourage large-scale installations and simultaneously exclude smaller configurations (Feuerbacher et al., 2022; Zhang et al., 2023).

While farmers could emulate the Delhi Agrivoltaics farmers by leasing their land to developers and earn a rental income, the lack of specific policy regulating agrivoltaics implementation processes means that there is no regulation ensuring fair compensation for farmers by developers (AVS Developer, 2024). Further, the farmers in this case received the added security of collaborating with their local KVK, which would not be the case for many other interested farmers due to limited capacity of a KVK centre to provide that nature of support (KVK Haryana, 2023). In addition, another agrivoltaics farmer has acknowledged the attempts developers and energy distribution companies made to take advantage of him that he only thwarted due to this pre-existing experience in the energy regulatory field (AVS 2, 2024). While this participant's experience will be elaborated on in further detail in the section discussing regulatory improvements below, such exploitative processes are not uncommon in renewable energy developments in India (Dutt, 2022; Dutta & Nielsen, 2021; Joshi & Yenneti, 2020). These challenges highlight extant distributive and recognitional injustices wherein a lack of regulation and support available to farmers, in addition to infrastructural and knowledge accessibility, increase a potential adopter's perceived risk and as a result may prevent further development and detrimentally impact perceptions of agrivoltaics (Lienert et al, 2015).

In addition, one agrivoltaics developer emphasised that while farmers are interested in agrivoltaics for the supplemental income the installations can provide, many are motivated to install agrivoltaics to keep their land in productive use before land prices are high enough to sell for commercial or industrial purposes (AVS Developer, 2024). In fact, these large landowners ‘are actually not really farmers […] they just own the land’ (AVS Developer, 2024). According to this participant, while these landowners may have been farmers ‘at least 30 years ago’, they now only ‘hire contract farmer[s] to work on the land’ (AVS Developer, 2024). Despite this distinction, their perspectives are more often considered by key decision- and policymakers, skewing regulation (GOI Employee, 2023).

In the Delhi Greenbelt, large landowners constitute most farmers with the capacity to participate in agrivoltaics developments, according to one industry perspective (AVS Developer, 2024). This agrivoltaics developer emphasised the fact that agrivoltaics development is not only inaccessible to many small and marginal farmers due to the lack of financial assistance but is also perpetuating existing renewable energy development structures that prioritise economic growth over farmer well-being.

> They [large landowning farmers] think that solar would be a stable income for 25-year period. And once the lease is over, the land prices will be really high. So, after that, they can sell it, or they can give it to some factory or residential projects can be constructed on that. So, this is what the farmers think. They are motivated in that sense.
>
> […]
>
> It’s very common in Delhi. If you’re asking, like if every—all the farmers think like that? Yes. In fact, if there was no Greenbelt rule which was protecting the land, they would have sold the land or constructed some commercial activity on the land way back (AVS Developer, 2024).

This prioritisation of projects installed by more affluent farmers, and landowners, that can afford it is in stark contrast to how agrivoltaics is presented in policy documents. Despite policy documents framing agrivoltaics and the policy itself as a vehicle for farmer welfare, the implementation of the policy has fallen short of its promises (National Researcher, 2023; AVS Developer, 2024). This is an insidious route for agrivoltaics if it were to become standard practice in India. Agricultural and pastoral land across the sub-continent has historically, presently been, and continues to be designated ‘wasteland’ or ‘unproductive’ to facilitate renewable energy installations and dispossess marginalised communities that might use the land in ways not considered productive enough (Baka, 2017). Previously (Chapter 5), we saw that agrivoltaics are not named in Component A of the Scheme. Yet, the Component allows for solar energy on ‘uncultivable’ agricultural land without further clarification, creating an opening for potential exploitation of this land designation (Baka, 2017). This approach may also be harmful for the proliferation of agrivoltaics as a renewable energy source as well, as it will engender the technology as one that reproduces large-scale solar energy systems that have a reputation for dispossessing rural and marginalised communities in India (Lakhanpal & Chhatre, 2019; Levien, 2018; Stock & Birkenholtz, 2021). Large-scale solar energy is already replacing fertile agricultural land in India (NGO 2, 2023), highlighting the risk of allowing agrivoltaics to be developed in a way that perpetuates this trend.

If acceptance is evaluated by the degree of economic gains as a direct result of a technology's implementation, then agrivoltaics can only become an accepted technology through large-scale developments (Alexandre et al., 2018). Already, elite stakeholders who participated in the development of the Scheme are concerned about the inability for smallholder and marginal farmers to engage with agrivoltaics due to the lack of financial assistance, disposable income, grid connectivity, and the size of their farm (GOI Employee, 2023). However, in addition to this, developers attempting to break into the agrivoltaics market in India acknowledged that agrivoltaics will never be feasible for marginal farmers simply because discoms and developers will not consider such developments as economically viable (AVS Developer, 2024). Marginal and rural farmers are already experiencing significant barriers to installing decentralised energy even with substantial subsidisation, so it is evident that agrivoltaics would remain inaccessible to such communities. As has been discussed Chapter 5, the Scheme was not designed for the sustainable implementation of agrivoltaics, and instead 'throttles' the technology (National Researcher, 2023).

This offers opportunities for more insidious risk of land conflict to marginal farmers and detrimentally impacting acceptability in the process. Despite agrivoltaics having been introduced as a technology that could address land conflict concerns (Ketzer, Schlyter, Weinberger, & Rösch, 2020; Trommsdorff, Dhal, et al., 2022), there is increasing risk of agrivoltaics following the same patterns that other historically dispossessive renewable energy projects have established in India. In earlier studies of pilot agrivoltaics sites in Germany, scholars have noted that while farmers can tolerate 20% crop yield reductions, there is concern that the visual impact on the landscape would consequently negatively affect acceptance (Torma & Aschemann-Witzel, 2023; Weselek et al., 2021); Torma & Aschemann-Witzel, 2023). Thus, greater consideration is provided for land use in German policy (Worringham, 2021). In India, despite the introduction of policies to encourage more widespread community uptake of solar, the technology's development has remained focused on large-scale systems (Sareen & Kale, 2018). Thus, visual impact and implications for land are less prioritised than generation capacity (Lakhanpal, 2019). A continuation of trends of this nature are thus expected to engender large-scale agrivoltaics (AVS Developer, 2024).

Furthermore, it is also due to this lack of regulatory support for agrivoltaics development that presents opportunities for financial exploitation of rural farmers by predatory loan schemes (AVS Developer, 2024). One agrivoltaics farmer in Maharashtra expressed how difficult it was to find a loan scheme that was offered at 'reasonable' rates and that he only avoided any exploitation due to his experience employed in energy regulation (AVS 2, 2024). Electrification efforts have been utilised to reinforce 'infrastructural and political power' of incumbent policy and policymakers in the two terms of Prime Minister Modi's neoliberal government (Singh, 2022: 405-6, 2024). Marginalised communities, including rural, smallholder, and pastoral farmers as well as Adivasi and Dalit communities, have been dispossessed of land viewed as 'unproductive' or wasted, and at times, community members themselves facilitate this dispossession in exchange for personal benefits from policymakers or regulatory bodies maintaining the incumbent political power (Baka, 2017; Singh, 2022). Incidents such as these increase feelings of distrust within rural farming communities and contribute to disincentivising solar acceptability (Singh, 2022; NGO 3, 2024). While discussions or reports of exploitative development practices have not yet been applied to agrivoltaics in India, there is growing evidence that existing implementation practices that facilitate unjust traditional solar installations may also facilitate unjust agrivoltaics installations.

For instance, details of this example have been asked to be omitted for this project, however one participant indicated that political corruption from the national to the state and regional level influence the development of solar energy, including its placement and financing, and voiced concerns over the future of agrivoltaics in this context (AVS Developer, 2024). Without financial assistance for agrivoltaics and with the current exploitative structure of some solar development processes that allow for corruption and predatory loans, agrivoltaics represent a risk to a farmer's livelihood that may not be worthwhile. This risk to livelihood and increased incidence of indebtedness due to lack of financial assistance, compounded with the unpredictability of agricultural income due to limited access to accurate information about agrivoltaics may contribute to reduced acceptability and subsequent adoption outcomes. The presence of regulated financial support for farmers interested in implementing an expensive technology like agrivoltaics would contribute to increased financial security, alleviate fears of exploitation, and may engender feelings of trust (AVS 2, 2024). However, current policy does not provide financial subsidisation or regulations on agrivoltaics financing. Thus, concerns of financial insecurity from predatory lenders remain, as evidenced by the experience of one agrivoltaics farmer (AVS 2, 2024).

Overall, economic benefits, barriers, and risks play a significant role in the future of agrivoltaics development. While much of the relatively small body of social acceptance of agrivoltaics literature mentions financial benefits as a condition of acceptability, the ability to sell energy for additional income as a main driver of agrivoltaics adoption is rarely mentioned. Notably, there are other, more prominent drivers for adoption, including the relative market advantages through the innovative use of land agrivoltaics premises (Torma & Aschemann-Witzel, 2023), a first step towards energy independence (Brudermann et al., 2013), and long-term preservation of agricultural land (Pascaris et al., 2020). While there are economic components of each of these motivations, they are closely linked with agricultural production and land preservation, rather than solely focused on the income the system could provide. Whether the farmers are large landowners in Delhi who are only interested in the income selling excess solar energy their agrivoltaics can provide or small landholding farmers in the Greenbelt, there are multiple documented cases from this research that indicate that Indian farmers are motivated by the ability to sell their electricity to the grid (AVS 1, 2023; SP 2, 2023). The attraction of a stable income when agricultural output grows increasingly unreliable has the potential to increase acceptability and ultimately adoption of agrivoltaics in India.

Nevertheless, this motivation prioritising financial security over other factors such as energy or resource security underscores a disconnect between the drivers of agrivoltaics in other regions of study wherein farmers are found to be more interested in energy security, or at least the provision of diversified income, and the large-scale Indian farmers that are interested in selling excess electricity back to the grid for the length of the lease period until they can sell the land itself. It highlights the disparity between who is interested in agrivoltaics and who can adopt it.

Despite the MNRE's intentions for policy to prioritise the 'small farmer' rather than the 'big guys' through the Scheme (GOI Employee, 2023), the majority of agrivoltaics developments are implemented by large landowners who do have the ability to afford the system, are likely to be more well-connected to the grid than marginal and smallholder farmers (or have the ability to contribute to grid upgrades), and receive additional income from energy evacuation to the grid. When agrivoltaics are only accessible by certain groups, in India's case meaning only progressive farmers or large landowners, then financial benefits over resource security would be determined the central drivers of agrivoltaics developments by key stakeholders. This distinction is significant because it skews existing understandings of the technology and contributes to assumptions that interested Indian farmers do not require robust financial assistance and correspondingly fosters agrivoltaics only in the large or commercial scale. This may contribute to a self-reinforcing feedback loop that continues to prioritise large-scale farmers that see agrivoltaics only as a stepping stone and a corresponding lack of policy that would foster more equitable scaling-out of agrivoltaics. It also contributes to the notion that agrivoltaics are only beneficial for the economic outcomes, rather than its holistic benefits across the food-energy-water nexus (Barron-Gafford et al., 2019), which in turn will impact perceptions of the technology in India as a technology not dissimilar from commercial solar energy. As the civil servant participant states, if the future of agrivoltaics 'encourages business as usual, then […] better not do it' (GOI Employee, 2023).

As expressed by the Delhi agrivoltaics farmers, agrivoltaics are perceived as an avenue for economic security, which enables them to produce their own energy while reducing costs and diversifying their income. However, this case may be an outlier representative because the current regulatory landscape prioritises a market-oriented approach to development. As will be discussed in the following section, due to uneven development, many rural farmers have unreliable, limited, or non-existent access to the electricity grid and are thus deprived of the benefit of selling excess energy. This motivating factor ultimately becomes a barrier that influences acceptability of the technology as well as its adoption potential.

6.2.2. Energy Security and Uneven Development

Energy infrastructure in India is widely viewed as being disjointed and unreliable (Dey et al., 2022; Sareen & Kale, 2018; Yenneti, 2016; Kale, 2014), but it has also been described as 'pathetic' (National Researcher, 2023) and of such 'substandard quality' that it is unable to support agrivoltaics in places (AVS Developer, 2024). It has been noted that the financial incentive of receiving additional income from the sale of excess electricity produced is a central driver of agrivoltaics in India. However, this capability is reliant on the proximity to the grid and the ability of a farmer to connect their solar system to it. For many rural farmers, especially in less-connected areas, this is simply not an option (KVK Haryana, 2023). For instance, one solar pump farmer from rural Haryana, is generally accepting of his solar pump installation, but he laments the inability to diversify his income:

> But this is fine, isn't it? I just can't get electricity from this. […] The solar pump can do up to two and a half acres per day, but if there is too much energy produced then it just goes to waste. Connecting to the grid is not allowed in Gurgaon district [region in Haryana outside Delhi] (SP 2, 2023).

This participant installed a solar pump to access reliable electricity and power for irrigation (SP 2, 2023). He was also motivated by the prospect of selling excess electricity to earn an additional income from agricultural production. However, after it became apparent that this was not an option post-installation, he has expressed a more ambivalent attitude now that the solar system is on his land for the entire 25-year lease period. In this case, without the economic benefit through the sale of excess energy or an ability to use the energy produced for anything other than irrigation, this farmer is simply 'fine' with his solar pump (SP 2, 2023). This indicates his overall acceptance of the system despite his preferences for changes that would increase the benefits of it. This point refers to the discussion of reluctant acceptance representing a spectrum of acceptance (Hai, 2019), illustrating this participant's general tolerance for the installation while also desiring improvements. Ultimately, he acknowledged that he prefers his electric pump to his diesel pump despite powering his irrigation being the only use he receives from it.

As this participant emphasised, the combination of unreliable infrastructure, the inability to connect to the regional grid due to this issue, and the consequent result of not being able diversify their income through the sale of excess electricity contributes to a more ambivalent perspective for decentralised solar among Indian farmers (SP 2, 2023). The central government promoting solar energy but disregarding the financial benefits of grid connection as a central driver indicates a failure to include farmers', especially rural farmers', views during the decision-making process. The issue with uneven infrastructure in India is one that is acknowledged by policymakers, as well as evidenced by the promotion of decentralised solar schemes such as the Scheme (GOI Employee, 2023). However, for many farmers, improved access for rural and off-grid electrification alone is not contributing to solar energy acceptance. Rather, some farmers are evidently interested in the financial benefits of selling energy to the grid because they have seen or heard about the successes of larger landowners (AVS Developer, 2024).

Furthermore, while this solar pump farmer's experience represents one case, it highlights the awareness among Indian farmers of the challenges associated with decentralised solar implementation. Despite national efforts to improve electrification and promote decentralised renewable energy through policies like the Scheme and existing supportive networks such as through KVKs, many farmers recognise the challenges they are facing with regards to resource insecurity and infrastructure.

> When you ask a KVK [Krishi Vigyan Kendra, or farmer capacity building centre] they tell you what you can do and how to install solar energy. But will it be good? This is the same with the government. The government should install electricity first [before telling us to install solar] (SP 2, 2023).

While generally accepting of his solar pump, this participant expressed his frustration with national electrification efforts and the responsibility put on farmers to install solar as an alternative response to uneven development. He favoured a more top-down approach to rural electrification and the assurance of accurate regulatory support and subsequent legitimacy afforded it, rather than the promotion of decentralised solar energy to farmers, aware that such installations may not effectively result in electrifying homes or diversifying incomes.

Nevertheless, solar energy remains an accepted and relatively more reliable source of electricity for decentralised farmers. Another solar pump farmer from Haryana described his motivation to install an off-grid solar pump on his land as due to the compounding factors of unreliable electricity in his village, poor infrastructure, and the unpredictable monsoons they previously relied upon:

> [We are] forced to stay with solar now. Before we relied on the rains [monsoon] that provided about 10% of water needs. But now the solar helps bring the water and keeps the lights on (SP 1, 2023).

September 2023—the time of my field visit—was uncharacteristically dry and represented an emerging pattern of progressively earlier conclusions to the Northwest's monsoon season (Jadhav, 2023), which resulted in farmers' increased reliance on groundwater irrigation. Due to the lack of reliable energy infrastructure in his region that would ensure dependable irrigation during drought, this farmer had opted to install a solar-powered pump to provide resource and livelihood security. As evidenced using the word 'forced' in his response, this participant indicates that he was not fully accepting of solar, potentially even reluctant to consider it, but recognised that the technology's installation on their land was the best option to continue agricultural production as their main source of income (SP 1, 2023). Since his farm was off grid, a diversified income through a solar installation was not seriously considered, however evidently energy security amid rising climate instability and lacking electrical infrastructure represent a key motivating factor for integrating solar energy into agriculture. This suggests that decentralised farmers in India are driven to install solar both for the resource security benefits, but also due to a lack of alternative solutions because of unreliable infrastructure. It also represents an emergence in reluctant acceptance for solar, or the spectrum of perceptions that can be applied to feelings of ambivalence or even apathy for a technology, despite adopting it.

The concept of reluctant acceptance, originating from nuclear energy studies, considers reluctance to apply to energy developments with which community members may have limited engagement in decision-making and development processes (Haikola et al., 2019; Mah et al., 2014; Pidgeon & Demski, 2012). Recently, the use of the term has expanded to solar energy studies to evaluate 'acceptance in principle', applying both to positive and negative-minded non-adopters (Hai 2019: 98). The negative-minded non-adopters in these cases can include individuals who are unaware of or feel reluctant about an innovation, which may also indicate a limited understanding of that innovation (Hai, 2019). However, this notion only considers reluctant acceptance in terms of non-adoption, rather than a component of the decision-making process, which ultimately results in adoption. In other words, the application of a reluctant acceptance perspective to solar energy has only been utilised as a lens through which to gauge willingness to accept, rather than applied to the spectrum of acceptance following technological adoption. This framework has also yet to be applied to decentralised solar energy or agrivoltaics in India wherein farmers are installing solar because it is the best option for them, despite their reluctance. Whereas solar acceptance in rural Indian agricultural communities may be because solar is the best, or only, option to access reliable energy, social acceptance of agrivoltaics in this context has not previously been considered. Thus, understanding the drivers, barriers, and risks for agrivoltaics acceptance becomes crucial.

In contrast to social acceptance literature that often evaluates acceptance based on adoption or willingness to adopt a technology (acceptability), the solar pump farmers interviewed exemplify a spectrum of acceptance that is little discussed. In addition to SP 2's general tolerance for his installation (SP 2, 2023), another solar pump farmer was first reluctant to adopt solar initially and only chose to do so because of unreliable electricity and monsoons, but now he describes his solar pump as 'wonderful' and is eager to hear about new innovations (SP 1, 2023). This evolution of acceptance, from reluctant to enthusiastic, is one that is acknowledged as a process that can result from access to accurate information and knowledge about the technology (Guo & Ren, 2017; Hai, 2019). The difference in this case however has been that this participant has had to learn by doing throughout the implementation process as well as living with the solar installation, both experiencing its benefits and challenges. Further, where age might play in role in accepting a new technology, this solar pump farmer's age (not specified but could be described as elderly) did not impact his willingness to accept solar (Hosseini et al., 2018; Keeley et al., 2022). Despite his early scepticism, he was ultimately open to change after considering the trade-offs of solar energy and resource security. Further, his standing as an elder and a progressive farmer integrating solar energy may influence other members in his community to consider solar energy as well (KVK Delhi, 2023).

However, just as this participant's enthusiasm may encourage other installations, the challenges he has faced post-adoption may just as equally influence non-adoption of the technology (Hai, 2019). For instance, this solar pump farmer's system had broken only 3 years post-installation, and at the time of our interview, was still awaiting repairs from the closest engineers available in New Delhi (SP 2, 2023). Multiple participants have experienced issues with the longevity of the solar panels installed through the Scheme (KVK Haryana, 2023), with one developer acknowledging that the Scheme can only afford to provide substantial subsidies for farmers if the materials used are of 'substandard quality' and likely would not 'survive' the 25-year lease period of the Scheme (AVS Developer, 2024). For such an enduring lease in which solar panels are contractually agreed to remain on a farmer's land for 25 years if they cannot afford the installation outright, it is the expectation that the materials would be durable enough to withstand damage from storms and depreciation from consistent use (KVK Haryana, 2023). While the installations at the KVK and this solar pump farmer's system were damaged in storms, the use of fragile solar panels may indicate a more systemic issue. If substandard materials are used to cheaply install solar panels, the systems themselves will be more fragile and susceptible to damage as a result. Combined with the long wait times for repairs and noted limited maintenance capabilities of farmers themselves (KVK Haryana, 2023), these panels were not built with longevity in mind. Rather, they may very well have been built to fulfil a government-mandated quota of solar installations (AVS Developer, 2024). Accordingly, there may be consequences for future uptake of decentralised solar, including agrivoltaics, among farming communities who view visible risks as outweighing potential benefits to 'their entire livelihood' (National Researcher, 2023).

When considering the additional materials and associated cost necessary to install agrivoltaics, it is evident that the quality of agrivoltaics will also be impacted if installed under an updated Scheme. While it was noted that an updated Scheme is currently under development that includes a stronger focus on agrivoltaics, one participant emphasises that installers of these solar systems under the Scheme have once again prioritised economic efficiency over technological and sustainable quality (AVS 2, 2024). The substandard quality of installations developed through this Scheme are already impacting perceptions of solar, so it is probable that the perceptions of agrivoltaics will likewise be detrimentally impacted (GOI Employee, 2023).

The simultaneous growing interest and awareness of complications post-adoption has influenced lower levels of acceptability, as evidenced by this solar pump farmer's account of his peers become less interested following learning about the complications he has faced (SP 1, 2023). This decrease in acceptability is further compounded by the first-hand accounts of farmers who have installed solar but whose opinions have become less-enthusiastic post-adoption and an inability to connect to the local grid (SP 2, 2023). The influence of poor infrastructure that prevents stable or any grid connection and substandard materials for solar installations has contributed to decreasing social acceptance of solar pumps and may influence similar perceptions of agrivoltaics going forward.

As such, the portrayal of decentralised solar, and agrivoltaics, as a vehicle for farmer well-being and improved rural electrification through policies like the Scheme has impacted the acceptability among farming communities. Ultimately, policymakers or other national stakeholders imploring farmers to install solar without the infrastructure to ensure the farmers themselves are not risking their livelihoods does not increase support but rather hinders it. Even when benefitting from some better infrastructure, agrivoltaics farmers within the Delhi Greenbelt believe that the central government should invest in infrastructure rather than asking farmers to shoulder the weight of rural electrification while, in their belief, taking credit for the improvements (AVS 1, 2023).

For example, under Component A of the Scheme, the ability to receive additional income from feed-in tariffs is contingent upon proximity to the grid. Even within the Delhi Greenbelt, where electrical infrastructure is generally more accessible, grid proximity is of little significance if another farmer connects and meets the ceiling first.

> What is happening is we have set up […] two and a half megawatts and the discom is saying that the market is fully loaded. Their capacity is full. If we want to build more, then we have to build a substation for that […] and there is just no subsidy for that (AVS 1, 2023).

The Delhi agrivoltaics farmers happened to be the first to install an agrivoltaics system that feeds into the grid, and consequently they have installed 2.5 MW of solar that fulfils the entire capacity of their local discom (KVK Delhi, 2023). Thus, if any other farmer from their region wanted to install agrivoltaics after viewing their relatively successful system or the demonstration site at the local KVK, they would be unable to receive the economic benefits unless they opted to upgrade the entire infrastructure. Without a subsidy for agrivoltaics, this additional cost is unlikely to be afforded. Even 'convincing' discoms to upgrade the infrastructure is a 'big task' (GOI Employee, 2023).

This indicates a degree of recognitional injustice wherein policymakers have shoehorned agrivoltaics into a policy aimed at engendering farmer welfare 'because they could' (National Researcher, 2023) without consideration for the rural, decentralised, or grid-disconnected farmers that would be interested in the promoted benefits (McCauley et al., 2017). The increasing attention to agrivoltaics in policy discussions within the central government underscores an acknowledgement of land competition and climate irregularity, however the limited recognition for how the majority of farmers—classified as marginal or smallholder—can participate renders such attention to agrivoltaics inconsequential. Ultimately, the Scheme misrepresents agrivoltaics because it fails to recognise the inability for average farmers to take advantage of it, which is antithesis to its promotion as a farmer welfare scheme. As has been expressed above and in Chapter 5, this fact can result in significant consequences for the future of agrivoltaics development in India. Specifically, awareness of challenges pertaining to Scheme inclusivity detrimentally impacts farmer perceptions of agrivoltaics, resulting in reduced levels of uptake beyond large-scale installations, and ultimately skewing long-term data on agrivoltaics acceptability and acceptance in India.

Despite the concerns for limited or non-existent grid connectivity and inadequate materials, there are issues regarding local and regulatory opposition to improvements that would contribute to mitigating these concerns. While the central government has promoted nationwide grid improvements and mitigating energy transmission losses, such improvements often indicate village electricity connections but not reliable energy (GOI Employee, 2023; Levien, 2022). Further, energy losses continue to occur with solar energy due to limited discom capacities and a lack of storage options (NGO 2, 2023). Solar pump farmers have acknowledged the inability to use the electricity they have produced outside irrigation or sell it back to the grid despite it being motivating factor (SP 2, 2023). However, this experience is also indicative of policymakers' disregard for the capacities of local energy authorities to support solar infrastructure, or even their willingness to facilitate solar installations. Existing policy stipulates that discoms are required to support a State-specific predetermined quota of decentralised solar development, whether through financing or grid-connection, and usually for solar pumps (NGO 1, 2023). However, stakeholders involved in implementation recognise that discoms 'hate solar' in general as they view the technology as 'competition' for their revenues and only begrudgingly allow installations when 'mandated' by the central government (AVS Developer, 2024). Without regulation or 'mandate', discoms consider agrivoltaics as even 'less profitable' than facilitating solar pumps and thus have 'no compulsion' to support its implementation (AVS Developer, 2024). This unwillingness to facilitate decentralised solar and agrivoltaics development hinders access to the technology, and in turn influences a corresponding unwillingness by farmers to adopt it due to the knowledge that there is limited or no support available to them. A corresponding lack of trust in institutions and regulatory bodies that would otherwise alleviate risk for renewable energy investments further contributes to decreased levels of acceptability and adoption.

While agrivoltaics research and development remains in its nascency and the technology may prove successful in providing diversified incomes and resource security, the limited availability of accurate knowledge based on research and experience, knowledge exchange, and co-production between farmers and elite, key decision-making stakeholders contribute to the lack of a proper enabling environment for the technology. Ultimately, the misrepresentation of agrivoltaics as introduced in the Scheme, the unreliable infrastructure that diminishes a decentralised farmer's capacity to diversify their income, and the limited financial and regulatory support exist as significant barriers to agrivoltaics acceptance. Although these barriers might be addressed through knowledge accessibility and exchange, the limited dissemination of accurate information remains another barrier contributing to reluctance.

6.2.3. Knowledge (In)Accessibility

Limited access to accurate information and opportunities to participate in knowledge co-development for agrivoltaics represent significant challenges and barriers to agrivoltaics acceptance among medium, small, and marginal Indian farmers. Indian farmers 'expect' financial subsidisation when it comes to solar implementation or electrification efforts (GOI Employee, 2023). The lack of such incentives in a widely promoted national policy such as the Scheme has caused and will likely continue to cause confusion and non-participation (National Researcher, 2023). Further, unclear information about the prerequisites required to install an agrivoltaics system, such as grid connection and upfront cost, contributes to this confusion and miscommunication. However, the limited availability of knowledge also represents an inability for farmers to make informed decisions, gain expertise and capacity to maintain their solar installations in the absence of local support, and contribute to knowledge co-production of sustainable, inclusive, and innovative configurations. Each of these factors engender an unsupportive environment for widespread adoption of agrivoltaics accessible to the average farmer.

In addition to reduced rainfall, the unreliable monsoon is also not contributing to groundwater recharging, which results in concerns over overexploitation of water resources (Khara & Ghuman, 2023; KVK Haryana, 2023). The solar pump farmers recognise that their borewells are exceedingly deep but have no other option but to continue to extract groundwater (SP 1, 2023). Yet, with improved interest in innovations, such as agrivoltaics, farmers struggling with water security may experience opportunities to provide more water efficient strategies for irrigation (Barron-Gafford et al., 2019; Giudice et al., 2021). Agrivoltaics research undertaken in arid regions have observed improved water efficiency due to the shade provided by the panels over agricultural beds reducing evaporation (Barron-Gafford et al., 2019). While these solar pump farmers' solar installations are configured in a traditional, low-lying system with limited space underneath to cultivate crops, their interest in further innovations indicates opportunities for future agrivoltaics development wherein agrivoltaics implementation policy could be motivated by mitigating groundwater depletion in India's arid northwest. However, this avenue for change will likely only be instigated through improved access to accurate knowledge for farmers who can, in turn, pressure decisionmakers to prioritise more sustainable energy policy.

Furthermore, despite concerns that agrivoltaics development could progress in a similar manner to large-scale solar energy as an exclusionary and exploitative technology (NGO 3, 2024), there are progressive farmers who are taking a different approach by fostering opportunities for knowledge exchange and capacity building for fellow farmers. One farmer owns 10 acres in Maharashtra and 'evacuates all power' produced from his agrivoltaics system. A former employee at the state Agricultural University and his local discom, this Maharashtra agrivoltaics farmer believed he had the capability, knowledge, and financial capacity to install agrivoltaics (AVS 2, 2024). He highlighted that he 'evacuates all power' and the electricity he produces supplies 'much needed' daytime electricity to seven surrounding villages who previously had to rely on cheaper off-peak (nighttime) electricity to farm (AVS 2, 2024). He emphasised that his expertise and capabilities meant that 'he had to do it [install agrivoltaics and sell the excess electricity]' and now leverages his experience to introduce agrivoltaics to other interested farmers (AVS 2, 2024).

While developers or owners of larger or commercial scale agrivoltaics installations may also track how the energy produced on their land is used as well, it was notable that this Maharashtra agrivoltaics farmer is proud of the community benefits his system is generating. Though he receives personal economic benefits through additional income from his installation, his acceptance and adoption of agrivoltaics was fuelled by the collective benefits he hopes to generate (AVS 2, 2024). Social acceptance of an innovation can be generated through fostering a sense of 'collective good', or a sense of contributing to social benefits, such as providing not only electricity, but electricity produced from renewable energy sources (Goyal & Howlett, 2020; Torma & Aschemann-Witzel, 2024). While renewable energy projects are observed as socially accepted due to the promise of social benefits, such as cheaper or cleaner energy, the acceptance of these larger projects has deteriorated because only landowners have benefited from rental income and wider social benefits are more invisible (Dunlap, 2017). Contrastingly, solar energy and agrivoltaics already foster a different diffusion of benefits due to the inherent decentralised nature of solar energy systems (Mulvaney, 2017). In other words, solar energy has the potential to be implemented in diverse configurations that can result in commercial-scale arrays or community micro-grids (Best et al., 2021). The same should be true for agrivoltaics given opportunities for experimentation and knowledge co-production by farmers. Improved dissemination of accurate information about agrivoltaics, experiential knowledge, and opportunities for knowledge co-production may result in improved interest, acceptance, and adoption of the technology among farmers and consequently, even result in innovative configurations (Joshi & Yenneti, 2020).

This Maharashtra agrivoltaics farmer exemplifies this trend through his enthusiasm and commitment to farmer capacity building and training about agrivoltaics implementation. In recognition of limited regulation and guidance for smaller farmers, this participant aims to contribute to filling this gap and fostering a local interest in agrivoltaics:

> Everyone [other farmers] appreciated it […] they said things like 'if you can do it, I can do it too. Help us, guide us,' (AVS 2, 2024).

The proliferation of 'champions' for agrivoltaics like this participant may increase awareness and acceptability of agrivoltaics among smaller farmers. Farmer-to-farmer networks are recognised as important avenues for establishing and building legitimacy and subsequent acceptance of an emerging technology because it exemplifies the opportunities associated with the technology from a trusted source (Mahto et al., 2021). In comparison to the lack of accurate information accessible to the average farmer, enthusiastic supporters of agrivoltaics committed to spreading awareness and contributing to farmer capacity building (AVS 2, 2024) advance support for the technology as well as foster of grassroots knowledge production in lieu of top-down support (Alexandre, et al., 2018; Jacobssen & Bergek, 2011).

Further, it may cultivate the emergence of more equitable agrivoltaics systems that prioritise collective benefits. Due to the technology's relative infancy, the future of agrivoltaics in India can only be speculated upon. However, with influential farmers and other community stakeholders such as this participant (AVS 2) promoting agrivoltaics through capacity building and knowledge exchange efforts, then assumptions surrounding the potential for more inclusive and community-focused configurations might be made. A commitment to disseminating accurate information, training opportunities, and supportive policy would be required to facilitate this outcome.

Many of the barriers introduced in this section underscore the importance of financial insecurity and knowledge inaccessibility. Farmers struggle to have their panels repaired due to experienced engineers largely being based in New Delhi, or other urban areas. However, farmers also are not required to receive training on how to operate or maintain their solar systems for the length of their lease period (NGO 1, 2023). The KVKs are recognised as an excellent resource for farmers and are available for farmers to receive training, but it is through their own discretion that they opt to do so (SP 1, 2023; SP 2, 2023). If maintenance infrastructure remains uneven, especially in more rural areas, it is imperative that farmers are required to receive training on how to operate and maintain their solar systems to prevent damage to the systems and encourage longevity. Utilising existing farmer networks may legitimise the requirement for training and contribute to ongoing knowledge exchange between farmers as they all would be learning-by-doing (KVK 1, 2023). For instance, if the solar installed are built using substandard materials, the farmers will not be able to accomplish much without extensive technical training, however efforts to encourage basic knowledge dissemination through capacity building opportunities would provide farmers with a good background understanding of what might be going wrong in the event their system is damaged. Despite challenges with limited skills training and development available to farmers for agrivoltaics, as well as limited interest by solar pump farmers in general, farmers are taking an interest in innovative technologies like agrivoltaics, the opportunities it can offer, and the ability to share their experiences and knowledge to inform others. Thus, there are opportunities for their enthusiasm to be harnessed to co-produce agrivoltaics research, provided that macro-level institutions recognise this potential and build on it.

6.2.4. Drivers and Barriers to Agrivoltaics Acceptance

While the overarching aim of the Scheme is to address this disparity in who can access and install solar energy, the Scheme has fallen short of its promises of providing simpler access to decentralised energy and agrivoltaics specifically. Farmers are beginning to realise this fact, as evidenced by the solar pump farmers' frustrations with their system maintenance and return on investment. Despite efforts to increase electricity accessibility by devising opportunities for distributed energy, the Scheme's developers have failed to recognise the structural barriers that exclude marginal and grid-disconnected farmers from participating in such a Scheme, only compounding existing distributional injustices. Further, they have disregarded the implications of installing substandard solar systems on lands owned by medium, small or marginal farmers who either cannot afford or access maintenance support infrastructure. It is understood that people are more susceptible to decision-making based on perceived risks or benefits, and if the risks or barriers outweigh the potential benefits, then acceptability can be detrimentally influenced (Lienert et al., 2015). The issues discussed above are expected to only be exacerbated when agrivoltaics are introduced (NGO 2, 2023).

If agrivoltaics remains only accessible to large landowners, it will ultimately result in significant and damaging trust issues for marginal and smallholder farmers (NGO 1, 2023). Understanding that farmers communicate concerns, enthusiasm, and other opinions through word-of-mouth, as observed through the one solar pump farmer (SP 1, 2023) and the Maharashtra agrivoltaics farmer's influence on their surrounding communities (AVS 2, 2024), the establishment of agrivoltaics in a manner reminiscent of exploitative renewable energy developments would irreversibly impact the social acceptability and adoption potential of the technology in these communities. This is notable because the opportunities agrivoltaics are argued to provide, including the benefits at the centre of the FEW nexus in addition to financial security (Gomez-Casanovas et al., 2023) represent opportunities for rural electrification and resource security for farmers at different scales in an era of unstable climate and agricultural production. However, if incumbent implementation processes continue, the potential for agrivoltaics to be implemented in inclusive and innovative configurations that are accessible to farmers at different scales would be detrimentally impacted.

Whereas promotion of renewable energy in other regions by elites may lend a sense of legitimacy to the technology, this is not necessarily the case in India (Fournis & Fortin, 2019). Instead, the importance of farmer-to-farmer exchange should not be discounted. One national NGO that facilitates economic development and sustainable energy system installation in rural, marginalised, and Adivasi (indigenous) communities underscores this critical factor:

> It [solar] may be recommended by your government officers or someone, but that particular person [another farmer with solar] will be like a champion for that [solar]. So, he [a potential adopter] will be accepting of the machines, he will know exactly what this machine can be, so he will utilise it to its fullest (NGO 3, 2024).

The participant understands that communities that have historically experienced marginalisation require a sense of legitimacy not from elites that have contributed to that marginalisation, but from other people within their communities. There is an observed rise in marginalisation because of renewable energy development in India (Stock & Sovacool, 2021; Singh, 2022), thus farmers will have more trust in testimonials from fellow farmers. As this participant has mentioned, acceptability has the potential to increase once farmers are aware of how the system works in practice, including its benefits and challenges.

Already, some marginal farmers broadly perceive agrivoltaics as 'encroaching' on agricultural land (SP 1, 2023; AVS 1, 2023). While for farmers who have only heard about agrivoltaics, the source of that knowledge being unknown, and having not actually seen or worked with an agrivoltaics system, foster concerns such as the solar pump farmers' can be explained as limited access to accurate knowledge. However, such concerns are also being raised with farmers who have installed agrivoltaics. The four farmers at the Delhi agrivoltaics site are considered marginal farmers who owned one acre each, pooling their land to install a collabortive system. While this has allowed them to share both the benefits and risks, one farmer on our walking interview still admitted that he perceived the system as an 'encroachment' because of the impact on crop production and its imposing presence (AVS 1, 2023).

Many farmers had similar responses regarding their motivations, highlighting the climate variability and uneven infrastructure that renders agricultural production increasingly more difficult (SP 1, 2023; SP 2, 2023; Hybrid Case, 2023). Solar pump farmers indicated that their motivation to install solar rested primarily on their ability to access groundwater and the limited alternative options available to them. Solar energy was presented to them as an opportunity to continue agricultural production and access cheaper electricity in the process. Despite the issues faced with ongoing maintenance of the systems, the farmers were generally pleased with the benefits the solar installations have provided them. While their perspectives ranged from tolerance and ambivalence, the solar pump farmer perceptions exemplified the spectrum of acceptance that may be portrayed in experiences with solar energy, emphasising that perceptions can evolve over time. Alternatively, developers and farmers who have installed agrivoltaics systems indicated that the financial incentive of selling excess electricity to the grid was the primary motivating factor (AVS Developer, 2024; AVS 1, 2023).

The attraction of diversifying income, or generating a more stable income, through electricity production cannot be discounted by farmers despite concern over the proliferation of this singular benefit impacting farmer perceptions of the technology. A notable outlier to these findings is the case of the Maharashtra farmer, who is pleased with the additional income, but was and continues to be motivated by the collective benefits his agrivoltaics system provides to the surrounding villages. These agrivoltaics farmer participants also highlight the importance of understanding the spectrum of reluctant acceptance wherein an adopter may be initially reluctant but grew more enthusiastic or remained apathetic as both valid perceptions of decentralised solar energy. Without such attention to lived experiences, there is little indication of how perceptions of solar systems have changed over time and might influence future developments. While it is beyond the scope of this project to conduct longitudinal studies of perceptions, the change in viewpoints can still be acknowledged through participant discussions of initial installation. Further discussion of this evolution of perceptions along the spectrum of acceptance will be applied to agrivoltaics specifically in Chapter 6 as a roadmap for agrivoltaics development in India emerges through farmer experimentation.

Reliable electricity is undoubtedly a driver for agrivoltaics and decentralised solar developments, however the recurring comments indicating that the monetary benefits of selling electricity to the grid are prioritised cannot be overlooked. Agrivoltaics literature largely attributes farmers with prioritising income diversification through energy security rather than solely focusing on the financial benefits (Pascaris et al., 2021). Furthermore, the larger landowners considering agrivoltaics systems as an opportunity for supplemental income prior to selling the land to other industries further emphasises the alternative perceptions of agrivoltaics in India in contrast to what has been observed in studies in other regions.

In a country with historically exploitative energy development pathways, with these perceptions, it might be argued that agrivoltaics could follow the same route. However, despite the risks of these perceptions and existing barriers to entry, there are also acknowledged opportunities for more widespread, and equitable, introduction of agrivoltaics. The drivers, barriers, and risks to agrivoltaics development discussed above highlight the importance of understanding farmer perceptions when evaluating the social acceptance and adoption potential of a new technology like agrivoltaics. It is evident that farmers are interested in the benefits that agrivoltaics can provide but experience roadblocks in sourcing start-up capital, uneven infrastructure, and limited knowledge accessibility. Nevertheless, participants have highlighted conditions that would encourage their potential uptake or continued acceptance of agrivoltaics.

6.3. Conditions for Acceptability: Reframing Farmers as an Equal Stakeholder

The following sections of this chapter will build upon the drivers and barriers introduced previously to discuss the conditions for social acceptability of agrivoltaics. Despite the challenges many Indian farmers face, stakeholders recognised the importance of empowering farmers to be treated as equal stakeholders in the agrivoltaics research, development, and implementation processes. Such empowerment would include the existence of supportive regulation, opportunities for capacity building and training, and knowledge co-development and experimentation.

6.3.1. Supportive Regulation

The lack of supportive regulation and 'reasonable' financing opportunities have been acknowledged by multiple stakeholders and farmers as the most significant barrier to solar and agrivoltaics uptake (AVS Developer, 2024; AVS 2, 2024; National Researcher, 2023). Supportive regulation might include specific policy addressed at the equitable and sustainable implementation of agrivoltaics, provide protections for farmers and the agricultural industry, and ensure that reasonable, or non-exploitative, financing schemes are accessible. Currently, the lack of these protections generates implementation practices that are biased towards those that can afford it, such as large-scale developments. Despite existing solar policies like the Scheme introducing agrivoltaics as an opportunity for decentralised, small, and marginal farmers, developers underscore that due to the high implementation costs and lack of government subsidisation, they pursue clients who can pay upfront (AVS Developer, 2024). This current focus on the commercial viability of agrivoltaics already excludes most Indian farmers who cannot afford the high upfront cost. In conjunction with discoms' consideration of solar energy as 'competition', unreliable and uneven infrastructure preventing grid connection, and limited skills development programmes render opportunities for widespread scale-out of agrivoltaics slim.

Considering these barriers, however, elite stakeholders have begun to consider alternative configurations and business models that would assist in the initial introduction of agrivoltaics and subsequently encourage pathways for improved regulation and financial assistance. While the limited financial assistance available for agrivoltaics has been repeatedly mentioned as a significant barrier to adoption, the underlying concern to this barrier is the lack of regulation for agrivoltaics specifically. Without specific policy that regulates the implementation of agrivoltaics and provides both legitimacy and transparency to the financing process, the immense cost of agrivoltaics installation and maintenance will remain a considerable risk for the average farmer (Goyal & Howlett, 2020; Jacobsson & Bergek, 2011). While Indian policymakers and developers are facilitating agrivoltaics installations in India, one government employee emphasised that countries with more experience have introduced policies that ensure the just implementation of solar energy on agricultural lands to generate a symbiotic system (GOI, 2023). Such policies include ensuring energy generation never contributes to a significant decrease in agricultural production or introducing strict guidelines for agrivoltaics construction and design (Worringham, 2021). In contrast, research focused on India remains largely in the feasibility stage with a few publications based on pilot installations. While these studies are critical additions to agrivoltaics literature, there are significant limitations as well, including the lack of testimonies based on lived experiences. The current strategy for solar installation in India prioritises increasing installed capacity at the lowest cost and is 'incompatible' with both the infrastructural capacity and social goals of rural electrification (Behuria, 2019). Agrivoltaics installation processes without specific regulation echo this strategy, indicating that only economically feasible, and thus large-scale, systems can go forward.

Additionally, the introduction of agrivoltaics via a policy that disingenuously promoted it as an avenue for farmer welfare illustrates limited regard for specific regulations based on best practices. While reports outlining best practices have been published since the introduction of the Scheme, none of these documents are codified or backed by policy (Pulipaka et al., 2024; Rahman, 2023). Rather, they are recommendations that developers may opt to acknowledge but equally may not until it is economically feasible to do so (AVS Developer, 2024; National Researcher, 2023). Consequently, the introduction of agrivoltaics in India is one that encourages the use of ‘business-as-usual’, and thus potentially dispossessive, processes of solar energy development (GOI Employee, 2023).

As has been mentioned above, if the introduction of agrivoltaics continues to encourage this business-as-usual pathway, ‘it would be detrimental to the whole system there [India] as well as the concept of agriculture’ (GOI Employee, 2023). This lack of regulation, and related limited financing assistance, has discouraged focus on how to scale out agrivoltaics for the average farmer (KVK Delhi, 2023). Developers are instead interested on how to implement agrivoltaics on a megawatt scale simply because it is the most cost-efficient for the additional materials required for a ‘traditional’ configuration of agrivoltaics, e.g. elevated panels, which require additional materials (AVS Developer, 2024). It is common, and expected practice to receive significant government subsidies for solar irrigation pumps in India and the Scheme does also include them in the Components unrelated to agrivoltaics (SP 1, 2023; NGO 1, 2023). However, without financial assistance for agrivoltaics farmers interested in solar will continue to install solar pumps rather than agrivoltaics. This will leave the agrivoltaics development to the ‘big guys’ (GOI Employee, 2023), eliminate potential for the technology to initiate equitable access to energy, water, and food production for smaller farmers, and ‘throttle’ new conceptualisations of agrivoltaics configurations or grassroots innovation (National Researcher, 2023; Joshi & Yenneti, 2020). In other words, agrivoltaics installations will continue to be developed in specific, conventional configurations of panels raised high above agriculture to allow for machinery, rather than facilitating new, innovative configurations that would be more effective for smaller-scale farmers who do not use machinery to the same scale or degree (NGO 1, 2023).

However, if opportunities for reliable, trustworthy, and ‘reasonable’ financial assistance were made accessible to the average farmer, it is likely that interest in agrivoltaics development would increase, thus consequently incentivising developers and discoms to assist in the installations (AVS 2, 2024). Similarly, some stakeholders already suggest an ‘India-centric approach’ (GOI Employee, 2023) to develop the ‘right’ business model for agrivoltaics adoption:

> Instead, what the scheme [PM-KUSUM] should do is leave it up to the market, saying where agrivoltaics makes sense […] Let the farmers come up with the solution (National Researcher, 2023).

While an explicitly market-driven approach might exclude small and marginal farmers due to limited financial capability, emphasising an alternative ‘India-centric approach’ that centres the majority small-scale farmer perspectives and thus capacity building and opportunities for farmer-driven development or participation in the development processes could encourage equitable agrivoltaics development (KVK Haryana, 2023). Scholars recognise that improved participatory approaches during decision-making processes would not only foster farmer agency, but also opportunities for 'bi-directional learning' between stakeholder levels that might contribute to a more equitable, accessible product (Goyal & Howlett, 2020: 316; Dunphy & Lennon, 2022). Improved opportunities for farmer empowerment within decision-making processes may improve social acceptability and even foster innovation (NGO 1, 2023). For instance, the case of the Delhi agrivoltaics farmers have adapted two different business models: land-lease rent received from developers and instituted a collective farming arrangement among them to create a single model that suited their situation (AVS 1, 2023).

Despite considering the system as 'encroaching' on their land (AVS 1, 2023), they have introduced an innovative configuration wherein they receive rent payments, additional income through feed-in tariffs, and 'share the responsibilities' of maintaining their system through their collective farming configuration (National Researcher, 2023). Such configurations allow for more disadvantaged, small, or marginal farmers to participate in the energy transition as it empowers them while also reducing personal risk (Krishnamurthy, 2021; Mahto et al., 2021b). This illustrates that a collective farming approach, already common in some parts of India (NGO 1, 2023), can be applied to agrivoltaics and indicates space for further adaptation of the technology to an 'India-centric' context (National Researcher, 2023).

Further, it fosters an interest in farming communities that otherwise might be systematically excluded from the solar transition and introduction of agrivoltaics (NGO 3, 2024). There have been '[wild] successes' with collective configurations for electrifying rural and disadvantaged communities through decentralised solar policy, however there is not currently an intention to apply this approach to agrivoltaics policy (GOI Employee, 2023). Nevertheless, as the Delhi agrivoltaics farmers exemplify, there are opportunities for discovering hidden potential and more inclusive scaling up of the technology in India if farmers' knowledge is considered, and existing policy supports varied configurations at different scales (Jing et al., 2022). However, there remains practical challenges for improving farmers' capacity to access the accurate knowledge to advocate for themselves, as developers and discoms would otherwise not encourage such models (AVS Developer, 2024), as well as capacity-building opportunities for maintaining and managing the system throughout its lifetime.

For farmers, the importance of more 'reliable' (AVS 2, 2024) financing schemes, knowledge exchange across stakeholder levels, and opportunities for capacity building cannot be overstated. Each of these factors generate a more favourable enabling environment for Indian farmers, the majority of whom are small or marginal scale and often expect exploitation, corruption, or dispossession from renewable energy development (AVS 2, 2024). When innovative solar energy systems are being deployed, it is imperative that the technology is accessible to those who might benefit the most from it. Indian farmers are some of the most 'economically deprived' (National Researcher, 2023) communities in the country and are recognised as unequal stakeholders in development processes, if not wholly left behind by the renewable energy transition (Singh, 2022; Walker, 2008). However, the existence of supportive regulation and reliable financing schemes may perpetuate more inclusive iterations of agrivoltaics and engender technological scale-out accessible to the average farmer. It is likely that this will require an increased focus on capacity building, skills development, and knowledge co-production, which will be discussed further below.

6.3.2. Capacity Building and Co-Production

Implementing an India-centric approach to agrivoltaics development will require efforts to increase skills development and capacity building opportunities for farmers. Community stakeholders have identified pathways of doing so, including through knowledge exchange, accessibility, and training via local KVKs, and encouraging interest by providing a purpose or justification for involvement (NGO 1, 2023). Thus far, concerns over limited financial assistance have reduced both the interest among farmers and consequently the necessary regulation that would facilitate agrivoltaics uptake (NGO 2, 2023; NGO 3, 2024).

Despite community-facing organisations emphasising the importance of capacity building, there are noted 'practical challenges on how to train them [farmers]' and how to provide avenues for knowledge co-production between the farming community and all levels of policy development (National Researcher, 2023). Such as dilemma will need to be 'cracked' (GOI Employee, 2023). Unfortunately, in current agrivoltaics research and implementation practices in India, such 'diversity of perspective […] is not so evident' from the view of developers and policymakers (National Researcher, 2023). In fact, it is virtually disregarded in the development of research and policy, including the Scheme (GOI Employee, 2023). Previous surface efforts to improve farmer participation during the stakeholder engagement process of existing decentralised solar policies, widespread engagement was 'not possible' and thus a complete understanding of farmer perceptions was not considered (GOI Employee, 2023).

Nevertheless, there remain significant challenges with awareness and access to accurate information. This lack contributes to growing insecurity among farmers with regards to technological interventions (NGO 2, 2023). As has been discussed, agrivoltaics will not only 'definitely cost more' but research and implementation experience has thus far been based primarily in Western countries where 'the temperature [and climate] profile [are] completely different (National Researcher, 2023). Based on the existing body of agrivoltaics literature, no single configuration or approach to agrivoltaics implementation can be developed to encourage or ensure accessibility or adoption (Biró-Varga et al., 2024; Jamil & Pearce, 2022; Randle-Boggis et al., 2021). Rather than a universal approach to development, a bespoke, context-specific approach will be required to address the specific needs and limitations of energy generation, agricultural production, and resource (in)security. In India's case, financial security and risk reduction for farmers, conservation of agricultural land and existing farming practices, energy poverty, and freshwater security particularly in the northwest are critical challenges that can and should be addressed by agrivoltaics development (Khara & Ghuman, 2023; Mahto et al., 2021b; Srinivasa Rao et al., 2019). As concerns that overwhelmingly impact rural and small-scale farmers, consideration of equitable agrivoltaics scale-out among these communities is crucial.

The facilitation of an India-centric approach is dependent on corresponding capacity building for the farming community for whom which the agrivoltaics systems will, and should, be primarily benefiting. The first step in building capacity is improving access to accurate knowledge from experts and other elites. In addition, to improve research quality, especially in new contexts like India or decentralised settings, it will be critical to encourage knowledge exchange from farmers' on-the-ground experiences with experts, researchers, and key decision-makers (NGO 2, 2023). Indian farmers are already understood as adept at learning by doing (KVK Delhi, 2023). However, their experience with agrivoltaics and solar integration could be enhanced through improvements from knowledge exchange through capacity building networks, which might facilitate trust in new interventions. Opportunities to do so may result in a greater capacity to make informed decisions, mitigate and adapt to potential risks, and address problems should they arise. Likewise, their experience adapting the technology could provide essential insights for wider agrivoltaics scale-out at different scales and infrastructural capacities.

For instance, solar pump farmers have expressed interest in new research emerging from institutions such as KVKs and national research bodies such as the Indian Council for Agricultural Research (ICAR) (SP 1, 2023). This hunger for new knowledge indicates an interest in not only new innovations but also emphasises an interest in improved participation and knowledge exchange, if the opportunities were more widely available. For instance, when asked about whether he had any say in how the solar irrigation system was installed on his land, such as the design or configuration, one solar pump farmer seemed genuinely surprised that he would even be asked about his role:

> Gave advice? Can we even do something like this? (SP 1, 2023).

For this participant, he did not consider that he would have an opportunity to participate or even influence how his solar system was installed. In India, developers generally make these decisions themselves after the farmer has opted to install solar (GOI Employee, 2023). However, the prospect of more participation in 'co-evolutionary learning' not only interested this participant, but also enabled discussion of on-the-ground insights and aspects of how the system would have been changed or configured differently if he had played a role in its design (Klerkx et al., 2021: 458; SP 1, 2023). This participant indicated that he would have preferred the system to have more panels because the '[ground]water is at a greater depth' and such an increase would have made the system more efficient

(SP 1, 2023). While this would have meant more ‘encroachment’ of his agricultural land, he suggested the compromise that the panels could even be raised higher, ‘[hitting] two or three meters high’ (SP 1, 2023). Evidenced by this participant’s consideration of solar installation updates reminiscent of agrivoltaics, farmers are open to thinking innovatively and having a larger, participatory role in solar development if provided the opportunities to do so. This notion also contributes to the development and design of energy installations that lend additional agency to farmers—the energy producers and users—and facilitates potential word-of-mouth spread of acceptance. Subsequently, it may also engender future opportunities for knowledge co-production (Goyal & Howett, 2020). However, despite this potential, there remain few opportunities for decentralised small and marginal-scale farmers to participate in decision-making or influence design and configuration of solar developments, even when installing a well-established, accepted technology such as solar irrigation pumps.

If both farmers and other stakeholders agree on the importance of equal participation throughout the process, from design to installation to end of lifetime, then the solar installations themselves may end up being more effective, sustainable, and just.

> If you want to engage a farmer on a long-term basis, maybe [5, 10, or 50 years], then you need to make a very clear projection for them […] The broad framework needs [to] develop in consultation with the farmer or any of those who are involved in this process (NGO 1, 2023).

Otherwise, without consideration of farmer perspectives and experiential knowledge, the potential for rejection remains.

> So that’s why I’m saying [that the] farmers’ engagement [is necessary]. Consultation is very much required. Otherwise, you [will] find a backfire kind of thing (NGO 1, 2023).

However, if more knowledge or capacity building opportunities were available to farmers, including related to agrivoltaics but also of different configurations for solar more generally, then new innovative designs might result from the uplifting of farmer knowledge. Further, opportunities for adaption and experimentation may produce ‘unexpected’ but more effective configurations for that specific context that may, in turn, encourage further social acceptance and adoption (Liu et al., 2020: 55). If developers and other elite stakeholders elevate the perspectives of farmers and their lived experiences, while understanding that solar installations on agricultural land requires multidisciplinary thinking rather than considering the energy generation and agricultural cultivation as separate aspects that may impact each other, then the installations themselves may evolve to adapt to an Indian context.

Currently, solar developers are argued as keeping electricity generation and cultivation separate, rather than treating them as elements that affect the other, and this treatment is one reason why solar installed under existing policy uninformed by farmer experience has a shorter lifetime than they are promoted to have (AVS Developer, 2024). The use of substandard materials in the Scheme for subsidised solar installations has already been demonstrated, however the poor implementation of solar can also cause difficulties accessing certain aspects for maintenance, resulting in the panels degrading faster (Aboagye, et.al., 2022). When it comes to solar and the wider energy transition, the 'biggest problem is still that of their maintenance' (KVK Haryana, 2023), thus it is not enough to consider the perspectives of farmers pre-adoption but rather consider their perspectives and lived experiences throughout the lifetime of the systems. This will require long-term training including ongoing maintenance and how to support the system over the 25-year lease period required for such developments in India. The lifetime of the systems throughout the long lease period, considered too long by many farmers (KVK Delhi, 2023; AVS 1, 2023) but also by developers who have key insights into the quality of the infrastructure and technological materials being utilised (AVS Developer, 2024). However, if the quality of infrastructure and materials are prioritised, it is likely farmers may have more trust in the technology and the idea of installing the systems for an extended period. However, the current lack of trust in the infrastructure, the discoms, and the limited access to accurate information and training opportunities for agrivoltaics contribute to lower acceptability.

6.4. Re-framing and Empowering Farmer Knowledge

The significance of capacity building highlights the important role KVKs and NGOs will play in the future of just transitions, which may include agrivoltaics. The development of research by KVKs for agrivoltaics as well as for other integrated solar systems, such as rainwater harvesting and water recycling efforts, generates evidence for farmers on how to not only install agrivoltaics but also integrate solar energy into agricultural systems (KVK Delhi, 2023; KVK Haryana, 2023).

Nevertheless, the existence of this research and available opportunities does not guarantee that a farmer will take advantage of them, such as in the case of one solar pump farmer participant (SP 2, 2023). Like this participant, farmers may choose to install a solar irrigation system without receiving training prior or post-adoption, which will influence their less-favourable perceptions of the technology (SP 2, 2023). Thus, as a few community stakeholders have indicated, providing farmers with a 'purpose' or justification for involvement may positively influence perceptions and adoption outcomes (NGO 1, 2023; AVS 2, 2024). One participant from an NGO specialising in integrating equitable solar irrigation in Punjab emphasised the importance of providing farmers with accurate guidance and a purpose:

> What is interesting […] is that [when] the farmer is getting real-time and good advisory [they follow it] […] The economic incentive we offered [was] not very encouraging for them because they are finding value in the system and the machinery. So, they say "it certainly reduced my water footprint, it reduced my energy footprint also. So, I don't need an economic incentive for that as well." So, that's why I'm saying if you have a very clear demonstration of activity and they understand the importance of solar, then the uptake will be very fast (NGO 1, 2023).

This re-framing of the technology through knowledge exchange as a 'holistic', 'clean development mechanism' is suggested to be a 'game changer' for agrivoltaics in India (NGO 2, 2023). If farmers can understand the 'why' of solar development, either through energy or water savings (NGO 3, 2024), or their contribution to climate mitigation efforts (NGO 1, 2023), then they may be more likely to adopt the technology. In other words, an increased focus on farmer knowledge and existing capabilities, in conjunction with efforts to improve those capacities through up-skilling efforts, may have a positive impact on their willingness to accept decentralised solar, and even agrivoltaics (Sovacool et al., 2016a).

These factors contribute to the creation of an effective and sustainable enabling environment for agrivoltaics. While financial assistance will be critical to introduce and diffuse agrivoltaics among farmers in India, opportunities for capacity building are just as crucial. These opportunities not only introduce the concept of the technology and its potential benefits but also provide opportunities for knowledge co-production where before there was limited exchange between stakeholder levels. However, as NGO 1 highlights, providing a justification for why agrivoltaics may benefit farmers beyond the widely acknowledged economic benefits, such as wider climate mitigation and resource security, as well as informing them of their role in such efforts, may engender further acceptance and adoption. It may also be true that improved access to knowledge and capacity, as well as the sense of fulfilling a purpose through their decision-making, may result in less government incentivisation in the long-term (Handgraaf et.al., 2013).

Evidence of farmers leveraging their own experiential knowledge and local agricultural practices are already recognised by community-based stakeholders as potential avenues for exploration for agrivoltaics scale-out. In Punjab, a state northwest of Delhi and bordering Pakistan to the west, there is culture of communal agricultural practices that lends itself to the proliferation of a collective structure for agrivoltaics wherein farmers share both the benefits and the risks through the introduction of a MW-scale system across multiple, shared land parcels (NGO 1, 2023). An NGO based in New Delhi has focused on promoting sustainable agricultural methods through the introduction of solar energy on farmland in Punjab. With experiential knowledge installing solar irrigation pumps and monitoring systems in these generational collective farming communities, the Centre Director views agrivoltaics as an opportunity with a 'good future' (NGO 1, 2023).

> Farmers are already using solar farmers for [a while] because we provided them with the knowledge, and we convinced them to use solar. […] There is a good vibe for agrivoltaics in India and other parts of the world. But [only] if you have a clear and concrete policy indication, we have a clear engagement policy with the stakeholder [developer], plus an economic model in place [including] who will get [what and how] and [in what time frame], then it becomes reliable. This is how you can achieve energy justice (NGO 1, 2023).

Since solar pumps are generally considered a familiar and accepted technology by farmers in Punjab specifically, this participant suggests that agrivoltaics are just one step further if opportunities for capacity building are generated. Likewise, developers have indicated that this collective approach to agrivoltaics may be feasible within the current business as usual context. In a general sense, large landowners may choose to install an agrivoltaics system on their land and hire day labourers, or marginal or landless farmers, to cultivate the land. This option allows for the landowner to supplement their income while also providing a stable income for the marginal farmers (AVS Developer, 2024). Nevertheless, it is evident that alterations to this model will be required as the farmers at the AVS 1 site have implemented agrivoltaics utilising a collective-use structure. They illustrate that with the right financing mechanisms and knowledge accessibility, farmers may be able to independently install collective agrivoltaics systems (AVS 1, 2023; NGO 1, 2023).

Another potential model mentioned by participants is the retrofit of existing large-scale solar parks into agrivoltaics systems. This would entail converting an existing solar installation to an agrivoltaics site by planting small, shade-tolerant crops underneath the panels, and because the panels on traditional solar parks are built close together, no farm machinery would be feasible (SP 1, 2023; NGO 3, 2024). Thus, day labourers or marginal farmers would be able to 'cultivate by hand' and again earn a stable income whereas before they might not have been able to (AVS Developer, 2024). This is an interesting scenario as it works within the existing business model that prioritises large-scale developments, but it does also address the need for sustainable livelihoods for a large agricultural industry and some of the most 'economically deprived' individuals in India (NGO 2, 2023). However, the conversion of utility scale solar parks into agrivoltaics developments has neither been attempted previously nor has it been researched as a possibility at time of writing. Therefore, there is little indication of how successful or efficient such a system would be. Studies that have calculated the land equivalency ratio (LER), or the calculation of land productivity, of large agrivoltaics sites to be between 150 – 200% (1.5 or 2 times the productive output of a land area) have based their projections on installations that have allowed for raised structures and wider spacing between the rows of panels to allow for ample sunlight and farming equipment to get through (Trommsdorff et al 2021; Schindele et al, 2021). Without both the large-scale of the system plus the efficiency of using farming equipment to cover the acreage needed, there is the possibility that the retrofit of existing systems will have an LER equal to or less than a traditional solar park or farmland, which may disincentivise such conversions. Nevertheless, there is limited information on whether this is a possibility and is a potential route that deserves further research.

Despite the potential of the collective structure, there are concerns for land conflict among the landowners and farmers. Progressive farmers are often no longer farmers themselves, but landowners that hire farmworkers (AVS Developer, 2024). In these cases, despite the farmers cultivating the land, they are not at liberty to make decisions on what to cultivate based on climate conditions. Instead, landowners as former farmers themselves often dictate crop production based on market demands, which may not always line up with the daily experiences of the farmers. This nature of relationship has resulted in land conflict historically (Khara & Ghuman, 2023; Singh, 2022), and it is expected to 'inevitably' occur under this model for agrivoltaics as well (National Researcher, 2023). According to one researcher at a national-scale research institution, this collective model is possible, but if it continues to operate under the business-as-usual system, it is ultimately not sustainable (National Researcher, 2023).

It is imperative that regulatory and financial headway is made to engender equitable introductions of collective agrivoltaics, as some NGOs and farmers have argued (NGO 2, 2023; NGO 3, 2023; KVK Haryana, 2023). The collective model may be an innovative pathway for agrivoltaics adaptation to the Indian context because it recognises that the average farmer does not have access to the amount of acreage needed to install a megawatt-scale system and thus see a faster return of investment. Rather, if a collective structure is encouraged, it allows for marginal or smallholder farmers to share the benefits, responsibilities, and the risks of agrivoltaics development. It allows farmers to share the installation costs without fear of gambling their livelihood and sole source of income and may reap the benefits of reliable electricity access and protection from climate variability. Further, by its nature, this collective structure distributes the benefits of agrivoltaics to a larger share of small farmers rather than holding the benefits for large-scale landowners. In truth, this structure has the potential to support the small farmers in the way that the Scheme initially set out to do (GOI Employee, 2023).

Agrivoltaics is understood as requiring input from the agricultural community to develop the most effective, efficient, and sustainable systems (Kumar et al 2024; Trommsdorf et al, 2024). Where there is concern over land conflict during conversations of agrivoltaics, it is imperative that not only community perceptions of the technology are evaluated pre- and post-adoption, but also that the farming communities' knowledge and lived experiences play an equal role in designing and configuring these systems. Despite this understanding, agrivoltaics in India are currently following the existing model of solar energy development that prioritises large or commercial-scale developments, economic efficiency over community benefits, and has historically dispossessed or exploited agricultural communities across the subcontinent (AVS Developer, 2024; Dutta & Nielsen, 2021).

Reframing agrivoltaics as a holistic system within India or fully embracing the conceptualisation of the technology as anchoring the FEW nexus and promoting it as such, will improve not only perceptions of decentralised solar and agrivoltaics and encourage acceptability, but also long-term experiences with the technology as it is adapted to a small-scale Indian context as well. Coincidentally, this reframing would contribute to a more accessible enabling environment for most India's farmers and consequently foster opportunities for farmers themselves to become an active and equal stakeholder in the development process. Accessibility of knowledge provides farmers, or potential adopters in this case, with the information and consequently the capabilities necessary to make an informed decision on whether to adopt agrivoltaics or not. If farmers do not have access to such information, then they cannot make an informed decision (Heffron et al., 2021; Jenkins et al., 2016). The provision of a just energy system is ultimately dependent on adopters and potential adopters taking an active role in not only the stakeholder process but also ensuring that they have reliable access to accurate knowledge that will allow them to make informed decisions (Heffron, 2022; Sovacool et al., 2016). To develop successful and supportive policy for agrivoltaics, it is critical that important insights from farmers, including potential benefits and implications, are considered.

The development of capacity building opportunities for farmers at different scales will provide them with knowledge and skills previously available to experts and effectively re-introduce farmers as equal stakeholders in the renewable energy transition. Further, there is hope that this skills development and improved active role in a community-focused energy transition will include formerly disadvantaged and overlooked groups, such as Adivasi (Indigenous) communities (NGO 3, 2024). Ultimately, considering diverse perspectives and knowledge may generate innovative adaptations to agrivoltaics configurations, and providing diverse communities with the skills to experiment and adapt may further contribute to this adaptation generation. This can only be achieved through the empowerment of farmers to become equal stakeholders in the research, development, and implementation processes of agrivoltaics.

6.5. Condition for Acceptance: Farmers as Equal Stakeholders

As has been discussed throughout this chapter, Indian farmers have concerns and invaluable insights based on everyday experience with solar energy on their agricultural land that could benefit the development of a more equitable agrivoltaics policy. One participant from the central government has acknowledged that efforts for stakeholder engagement in preparation for drafting the Scheme have not had the reach they originally intended due to concerns over an 'unending discussion spree' (GOI Employee, 2023). However, the lack of farmer engagement from various agricultural communities, including but not limited to marginal, rural, and Adivasi farmers, is evident in the creation of a solar subsidisation policy that 'stumbles' at the implementation stage (AVS Developer, 2024). The uneven electrification, maintenance, and support infrastructure, lack of financial assistance without fears of exploitation, and limited access to accurate knowledge and capacity building opportunities all contribute to distrust and lack of confidence among farmers. For an agricultural community that has 'faced a lot of injustices' from both the government and the private sector (NGO 1, 2023), encouraging mutually beneficial partnerships between stakeholders wherein the farmers have a 'prominent voice' will raise confidence levels (Wallsgrove et al., 2022).

Despite the barriers and risks to farmers' livelihoods, farmers and community facing organisations remain optimistic about the future of agrivoltaics in India. One participant suggested that making such an effort will encourage confidence in agrivoltaics beyond India and in most South Asian countries (NGO 1, 2023). While any discussion of other country settings is beyond the scope of this project, it is notable to acknowledge this NGO participant's confidence in the future of agrivoltaics in South Asia, given that opportunities for capacity development and knowledge co-production are provided for just implementation.

The social acceptability of agrivoltaics is strengthening in India and among smallholder farmers specifically, as exemplified by the interest in further innovations from solar pump farmers. However, the lack of accurate information available to farmers renders introducing agrivoltaics and corresponding implementation mechanisms inaccessible and consequently prevents the farmers from adopting it. Essentially, the lack of a proper enabling environment for agrivoltaics is throttling its development in India (National Researcher, 2023). However, if there were increased opportunities for collaboration, farmers could potentially access accurate information about agrivoltaics and in turn provide academics and policymakers with important insights on implementation and cultivation best practices within specific Indian contexts at various scales. While this aligns with established social acceptance literature for renewable energy projects (Pascaris et al., 2021; Moore, 2022: Torma & Aschermann-Witzel, 2023), for such a new technology like agrivoltaics, it is difficult to predict how a willingness to accept translates to acceptance post-adoption. This is largely due to limited social acceptance research conducted on established agrivoltaics projects, specifically in India and other emerging economies. However, it is evident that Indian farmers are thinking innovatively and are interested in effective adaptions to solar energy and agriculture that renders both practices more sustainable and equitable for them and their communities. Ultimately, discerning the determinants of social acceptance assists in shaping a wider understanding of community energy and resource needs, and subsequently implement more equitable agrivoltaics systems and just energy transition in general.

Despite past experiences as excluded from decision-making, if farmers are treated as an equal stakeholder through the design, implementation, and lifetime of agrivoltaics, then overall acceptance of the technology may increase due to the existence of trust placed in their experiences, perspectives, and knowledge. Subsequently, other crucial stakeholders across governmental, policy analysis, and grassroots organisations and within the agricultural sector will believe that agrivoltaics has a future in India because of the support from farmers. Achieving energy justice is the preferred outcome for agrivoltaics implementation, and is dependent on the creation and deployment of equitable processes that involve farmers that have otherwise not had opportunities to participate in. In other words, improving opportunities for farmer participation in development and implementation processes would simultaneously enhance the overall perceptions of the technology and process itself. Facilitating more transparency in the development process will also reduce perceptions of risk and distrust (Lienert et al., 2015). An improvement in trust in the support structures and regulatory bodies bolsters legitimacy and may encourage more adoption of agrivoltaics and even engender the creation of further adaptations and new knowledge to inform further innovative configurations.

The development of equitable processes requires highlighting the farmer perspective rather than an industry perspective, as has been the norm thus far. Without the collaboration between stakeholders, accessibility for farmers, and accountability and transparency for decisionmakers and developers, it is likely that agrivoltaics will not be successful. Attempting to implement agrivoltaics in a business-as-usual manner will perpetuate existing trends of dispossession and exploitation that farmers are but should not be used to. In the words of one elite stakeholder, decisionmakers viewing agrivoltaics as a solution for which they are now looking for a 'problem to solve' (National Researcher, 2023), agrivoltaics is not currently positioned to benefit the wider farming community. Without considerations for the farmers who will be the adopters of this technology or considering their conditions for accepting such an innovation, wider social acceptance of agrivoltaics is likely to be greatly and negatively impacted. Trust, legitimacy, and opportunities for equal participation ultimately contribute to social acceptability outcomes. With these factors, the co-development of an equitable energy transition that benefits institutions and regulatory bodies because their end-users (the farmers) trust their decisions, thus legitimising those decisions because they are based on community perspectives and experiences, generates social acceptance among those who have been excluded previously. Without them, agrivoltaics in the technology's current iteration will continue to be rejected and instead, *jugaadu* farmers might experiment independently with the resources that are available to them, such as solar pumps. If it perpetuates, this process may render agrivoltaics another top-down, commercial-scale technology that neither benefits the farming communities nor can be scaled out in any just way.Ultimately, adoption perspectives are co-dependent on equity and justice discussions. While economic feasibility and ecological sustainability are noted as key drivers of agrivoltaics development, 'social fit' (Alexandre et al., 2018) remains an important aspect that thus far has been overlooked in India. There are significant barriers and risks to agrivoltaics implementation for most farmers in India, many who are classified as marginal, smallholder, or decentralised. Therefore, the technology is primed to be re-framed and adapted to more accurately reflect the reality of Indian farmers, such as through the creation of innovative configurations and designs not widely observed in existing literature or pilot studies. With the increasing focus on both decentralised solar and agrivoltaics individually, it is surprising that the two technologies have yet to be combined in new and unique ways within policy and academic discussions. Nevertheless, farmers are interested in new adaptations to decentralised solar and the potentiality of agrivoltaics, even without an enabling environment available to them. Despite farmers not yet being considered equal stakeholders throughout the development process, they are poised at the frontier of experimentation and innovation that may provide a roadmap for agrivoltaics in India.

Indian farmers and participants from grassroots organisations have acknowledged the innovative nature of agrivoltaics and have expressed interest in the technology, highlighting the innovative mindsets of Indian farmers. While they are interested in the technology and are willing to accept, their acceptance and ultimate adoption is dependent on the creation of an enabling environment that engenders the equitable and just introduction of agrivoltaics. Such improvements to the enabling environment for agrivoltaics involve the provision of accurate information, open channels of communication to continue learning about the technology, training and capacity building opportunities for maintaining the technology over its lifetime or the 25-year lease period. Further, the promotion of both the personal and communal benefits of the system, such as providing farmers with the 'why', is expected by NGO participants to further improve acceptability (NGO 3, 2024). The creation of such an environment, however, is not a one-way, top-down route. Rather, it involves exchange of experience and knowledge between elites, experts, local organisations, community members and representatives, and the farmers themselves. In other words, treating the farmers as an equal stakeholder in the decision-making process is essential to encourage agrivoltaics acceptance.

The following chapter will further elaborate on how Indian farmers have the potential to and currently are disrupting the current systems of agrivoltaics implementation and contribute to a more accessible and equitable future of the technology in India. This chapter evaluated the existing barriers, risks, and drivers that influence perceptions and acceptability of agrivoltaics among the agricultural community. Employing an energy justice and social acceptance lens, this chapter also analysed the disconnect between the existing frames and policy of agrivoltaics and the reality of a deficient enabling environment for the technology that results in an ineffective system. While there are significant barriers and risks to agrivoltaics implementation for the average farmer in India, there has been little attention given to mitigating these risks at the policy level. Uneven development and electricity infrastructure prevents many farmers from reaping meaningful economic benefits, limited access and availability of information inhibits their ability to understand the implications of system configurations, and limited, reasonable financial assistance mechanisms hinder them from engaging with a risky technology. Ultimately, understanding the unjust processes and outcomes of solar development thus far in India and how they are informing current agrivoltaics policy, will assist in developing more equitable processes for scaling out agrivoltaics in India.

Essentially, the social fit of agrivoltaics in India is one that still requires adaptation. While the treatment of Indian farmers as equal stakeholders throughout the design and implementation processes will engender more sustainable, equitable, and just agrivoltaics within the country, the farmers are already displaying efforts to implement innovative agrivoltaics components into their cultivation practices despite the insufficient enabling environment. As shall be discussed in the following and results chapter, Indian farmers are utilising local knowledge to experiment with existing systems and decentralised solar and potentially disrupt the existing systems of agrivoltaics development. Rather than a technology that perpetuates exploitative structures of renewable energy implementation, agrivoltaics have the potential to be utilised as a tool for development for historically dispossessed communities.

Chapter 7: Disrupting Agrivoltaics Paradigms: A Roadmap for Development, Implementation, and Innovation in India

7.1. Introduction

The previous chapters examined the ways that agrivoltaics and decentralised solar-powered irrigation pumps are presented and perceived by different stakeholders in India, and under what conditions social acceptability becomes possible for stakeholders. For instance, major disparities between the presentation and implementation of an innovation will affect social acceptance, including for agrivoltaics (Kumar et al., 2021; Yenneti & Day, 2015). In India, agrivoltaics development will require further refinement for the technology to reach its potential as acceptable, equitable, or just. While agrivoltaics itself cannot alter existing systemic inequalities, the technology has potential to mitigate the effects of these inequalities through the holistic FEW nexus and socioeconomic benefits it is argued to provide. This chapter aims to build on these previous discussions to analyse current lived experiences with agrivoltaics and how these experiences inform a potential roadmap for agrivoltaics scale-out in India.

Agrivoltaics systems are being implemented in India through business-as-usual processes that emulate large-scale installations in parts of the Global North, often excluding farmers who cannot afford to participate in the transition for numerous reasons, including lack of financial support and specific regulation. This prevents important community knowledge and experience via small and marginal farmers from being considered when developing such specific policy (Kumar et al., 2021; Sareen, 2021). With a PM-KUSUM Scheme 2.0 under development expected to have more focus on agrivoltaics (AVS Farmer 2, 2024), improved consideration and participatory opportunities should be provided to the average farmer. In this case, the average farmer in India refers to the medium, small, and marginal-scale farmers that make up the majority of the agricultural sector (Government of India Ministry of Finance, 2020). This might include rendering the technology more accessible to them through reasonable financing schemes, improved knowledge dissemination, and sufficient infrastructure, as well as determining different strategies and configurations that improve social acceptance and technological feasibility within an Indian context.

While a large agrivoltaics system reduces the return on investment and increases the land equivalency ratio (LER) (Amaducci et al., 2018), this nature of configuration is not feasible for the average Indian farmer, who are classified as small or marginal. However, as this chapter will highlight, there are opportunities for and devised by farmers that are changing the paradigm of agrivoltaics implementation. There is evidence of small solar pump farmers using existing systems to install solar powered irrigation pumps as well as integrating agrivoltaics components through their own ingenuity.

A growing body of research argues for flexibility within energy transitions, including conceptualisations of agrivoltaics (Melnyk & Singh, 2021; Schindele, 2021b), however, policy and elite stakeholder perceptions of how agrivoltaics should look produces more strict definitions, and consequently 'throttles' agrivoltaics development and further innovation (National Researcher, 2023; Worringham 2021). As has been discussed in previous chapters, agrivoltaics' definitions are based on largely European, North American, and East Asian (predominately Japan and Taiwan) systems that employ different agricultural structures and more reliable grid connectivity and electrical infrastructure. Thus, to be applicable to the wider agricultural community, including the 70-90% of farmers classified as small or marginal-scale in India, (GOI Employee, 2023; NGO 1, 2023), Indian agrivoltaics must remain flexible in definition and avenues for experimentation must be both allowed and encouraged.

Overall societal acceptability in India has been influenced by the ineffectual introduction of agrivoltaics through the prohibitive Scheme and limited enabling environments for the technology. Only considering agrivoltaics through its static definitions as established by largely Eurocentric research and policy propagates large-scale systems not dissimilar to utility or commercial-scale systems that inhibit small-scale famers' abilities to participate. It also fosters an idea that agrivoltaics are only valuable for the personal financial benefits accrued rather than communal benefits, which further excludes any farmer with unreliable, outdated, or non-existent electricity infrastructure as well as innovative communal configurations.

Employing disruptive innovation and restorative energy justice perspectives, this chapter will examine current lived experiences with agrivoltaics and ongoing innovations to argue that more flexible understandings the technology and the encouragement of experimentation with agrivoltaics configurations will engender widespread uptake and new potential pathways for agrivoltaics scale-out in rural, decentralised contexts. To accomplish this, this chapter will begin by exploring the lived experiences of agrivoltaics to understand a wider spectrum of acceptance for this innovation in India. This spectrum of acceptance allows for critical consideration beyond the binary perspective of social acceptance versus rejection to examine the diverse perceptions individuals, communities, and key stakeholder groups may have for agrivoltaics. One Delhi village's agrivoltaics site will be utilised as a central case study for this section with two supporting cases, at one KVK in Delhi and another site in Maharashtra to complement the analysis. Subsequently, this chapter will introduce the hybrid case study in the state of Haryana wherein one farmer is disrupting the current trajectory of agrivoltaics implementation by leveraging existing financing and capacity building systems to innovate his farm's solar-powered irrigation pump. The purpose of this section is to emphasise not only the ingenuity of rural Indian farmers but also highlight another potential pathway for agrivoltaics implementation that disrupts the current paradigm of agrivoltaics installation in India and may engender restorative justice through a dual-use regenerative agriculture and renewable energy system.

7.2. Lived Experiences with Agrivoltaics: Evaluating the Spectrum of Acceptance

The previous chapter discussed the acceptability of agrivoltaics by referencing case study interviews with various stakeholders, including farmers who have installed decentralised solar energy on their agricultural land by way of nationally subsidised solar-powered irrigation pumps. Solar pump farmers expressed an interest in agrivoltaics but emphasised that their motivations focused on more reliable groundwater access and that previous and ongoing experiences with unreliable infrastructure, support networks, and limited capacity building opportunities would influence their decision-making (Solar Pump (SP) Farmer 1, 2023; Solar Pump (SP) Farmer 2, 2023). These barriers were recognised by these solar pump farmers, as well as other stakeholders involved in solar implementation (NGO 2, 2023; AVS Developer, 2024), as prohibitive of further solar development or innovation on their land. Nevertheless, participants discussed several conditions that would need to be met to encourage further adoption, the most notable of which being accessible and 'reasonable' financing opportunities (AVS Farmer 2, 2024).

An evaluation of acceptability pre-adoption is crucial for new innovations, however there is further merit in focusing on lived experiences with agrivoltaics and acceptance post-adoption. While a social acceptance lens has been applied to agrivoltaics in recent years (Pascaris et al., 2022; Torma & Aschemann-Witzel, 2023, 2024), there is a significant gap in the literature that examines social acceptance of existing agrivoltaics systems in general, as well as in a developing Asia context (Siciliano et al., 2018). Despite the conditions discussed to encourage further acceptance and equitable adoption of agrivoltaics (see Chapter 6), there are significant institutional and systemic barriers that are instead perpetuating exploitative and unjust processes of large-scale solar development (Singh 2022; Singh, 2024). It is assumed that this pattern will detrimentally impact the social acceptance of agrivoltaics, specifically at the community level (AVS 2, 2024), and influence how it is implemented. This section will analyse interview responses from agrivoltaics farmers and other stakeholders involved in agrivoltaics implementation and management. Subsequently, these results will be examined through the frameworks of energy justice, including restorative energy justice, and disruptive innovation to discuss agrivoltaics' future potential in India, particularly among previously and currently excluded communities.

Large landowners in India's Northwest perceive agrivoltaics as a temporary system to increase land productivity while waiting for land prices to increase enough to sell for industrial development (AVS Developer, 2024). While the implementation of private agrivoltaics developments remain in nascency, it has been argued by one agrivoltaics developer that the cost of installing agrivoltaics renders it unappealing and cost-ineffective for any other configuration but large-scale developments (AVS Developer, 2024). Market-driven energy transitions influenced by more Western, neoliberal perspectives contribute to the prioritisation of large-scale renewable energy systems in ongoing transitions (Kumar et al., 2021). This ‘regulatory inertia’ perpetuates path dependencies that establish large-scale systems as the ‘best’ way of achieving climate goals and/or electrification, even at the cost of local communities and ecosystems (Kumar et al., 2021: 80-81). Early scholarly consensus echoes this sentiment by arguing that agrivoltaics are rendered more cost-efficient the more acreage the system covers (Chandra Giri & Chandra Mohanty, 2022; Kim et al., 2020) and reinforcing this idea of efficient energy transitions. Moreover, agrivoltaics requires significant upfront investment unattainable by many small and marginal farmers, which further disincentivises feasibility and thus, interest. Without financial assistance through government subsidisation, as normalised in other kinds of solar development in India, agrivoltaics remain inaccessible to many farmers (AVS Developer, 2024). The combination of limited financial assistance and the influence of more Western notions of market-driven energy transitions indicates a trend towards large-scale agrivoltaics systems as well as installations motivated by broad positive outcomes, whether for financial gain or meeting energy goals. Despite this perspective’s exclusion of small-scale farmers who make up the majority of India’s agricultural landscape, this emphasis on financial gain is not only limited to large landowners in India.

7.2.1. Farmer Agency and Land Competition Concerns

In the Delhi Greenbelt, a mile-wide agricultural area encircling the nation’s capital, four small-scale farmers opted to combine each of their one-acre parcels of farmland to install 2.5 MW of agrivoltaics across four acres (Images 2 and 3). While this configuration is innovative in agrivoltaics installations, the communal land ownership is commonplace among Indian farmers and in this case, was driven by their desire for improved financial security (AVS 1, 2023). For these farmers, the sale of electricity to achieve a more stable income was identified as the central motivating factor for the installation and is still considered the most important part of the system by them three years post-adoption (AVS 1, 2023). Their novel collaborative configuration is one that benefits small-scale farmers by encouraging a shared responsibility of the system, including both a distribution of the benefits as well as the risks that was acknowledged as a potential condition for improving acceptability (NGO 1, 2023). This site exemplifies not only the prioritisation of economic benefits, but also the influence of incumbent perspectives in energy transition decision-making. While these rural farmers do not have access to the same level of financial capital as large landowners or developers, their decision-making was nevertheless influenced by entrenched market-driven perspectives.

[Image 2 (left): AVS 2 site within the Delhi Greenbelt (Author's Own, 2023)]

[Image 3 (right): AVS 2 site within Delhi Greenbelt (Author's Own, 2023)]

Using a modified photovoice methodology where one farmer participant directed me to capture an image of what he considered the most important aspect of the agrivoltaics system, this participant wanted the solar panels to be the clear focus of the image (Image 4). To him, and to the other farmers at the site, the solar panels were the most important part of the installation because they provided a 'double benefit' of a dual-use system (AVS 1, 2023). In this instance, not only do the farmers know that their crops are protected from harsh sunlight and extreme Indian summer temperatures, but because 'electricity is being generated on top!', it can be sold for additional income through a grid connection to their local distribution company (AVS 1, 2023). Referencing the photovoice image (Image 4), the solar panels are placed close together without allowing for much sunlight to penetrate to the crops underneath. For instance, while the turmeric present in this system is a shade-tolerant crop 'perfect' for agrivoltaics, the bananas cultivated here are not recognised as the same (KVK Delhi, 2023). Considering the close configuration of the panels and the acknowledgment by the farmers through the walking interview and photovoice image, it is evident that the Delhi agrivoltaics farmers prioritised solar electricity generation over agricultural production.

While the turmeric crop may flourish in this system, this farm's shady conditions limit the possibility of other crops with higher sunlight requirements. However, full responsibility for this design choice cannot be ascribed to the farmers alone. To improve farmer participation in this system's implementation, the developers considered the farmers' priorities in the design and with the assistance of the local KVK, the farmers chose to optimise energy generation. Three years along, the local KVK (a government-funded farmer capacity building institution) staff remarked that too little research was applicable to the Indian environment and agricultural context at the time of this system's development (KVK Delhi, 2023). Thus, attempts to facilitate participatory justice in the design of this system were ultimately hindered due to limited research available, contributing to less-informed decision-making. This configuration and development process emphasises a requirement for improved research on the impact of agrivoltaics in diverse conditions and contexts. This research focus will encourage a balance between ensuring farmer agency with improved access to information to make more informed decisions regarding agrivoltaics and which crops to be cultivated.

[Image 4: Participant modified photovoice image at AVS 2 site in Delhi Greenbelt, featuring the solar panels as 'most important' (Author's Own, 2023)]

Farmers' agency in decision-making processes and farmers opting to prioritise financial security in an increasingly challenging sector cannot be disregarded. As was discussed in Chapter 1 and 2, the Indian agricultural sector has been evolving under the current neo-liberal government, wherein many small and marginal farmers have 'moved out' of agricultural wage work and have at 'least one foot in non-agricultural sectors' to make ends meet (Lerche, 2021: 1387-8). As scholars have noted, it has been 'several decades' since the majority of India's farmers have been able to survive from agriculture alone (Lerche, 2021: 1388; Baviskar & Levien, 2021). Prior to the installation of their agrivoltaics system, the Delhi farmers were no different. They noted their previous experience taking on manual labour wage work, including contributing to cremation and other funereal services for additional income (AVS 1, 2023). When offered an alternative, poor farmers might experience brief hesitation before agreeing, such as one Delhi agrivoltaics farmer emphasised: ‘What else is a poor farmer like me supposed to do’ (AVS 1, 2023)?

The Delhi agrivoltaics farmers exemplify the adoption of overarching market-driven perspectives in the local solar and bourgeoning agrivoltaics industry, as well as highlight a trend that overlooks complex socio-cultural relationships that contribute to decision-making, such as power dynamics between rural farmer and developer, and the existence, or absence, of trust in regulatory bodies. On the surface, these farmers have prioritised economic security in an increasingly insecure agricultural market and have emphasised their flexibility in responding to climate challenges, economic uncertainties, and new opportunities that might alleviate those concerns. However, they have also reinforced existing academic concerns over agrivoltaics’ future wherein land competition between energy generation and agricultural productivity due to un- or mis-regulation consequently impacts general social acceptability of the technology (Torma & Aschemann-Witzel, 2023).

While these farmers only exemplify one specific case where solar energy generation was prioritised, if repeated on a larger scale, this would represent a shift in India’s small-scale agricultural sector with potential implications on community dynamics both within the local farming community as well as in relation with other stakeholders and elites, the environment through increased infrastructural proliferation, and on cultivation practices. Without a robust set of research to identify what these implications would look like in practice; however, this case exemplifies an emerging trend in agrivoltaics development in India that is reminiscent of many solar installations in the sub-continent. In these instances, the technology is framed as one that works with the community but the key decision-makers that promote it envision a community ‘compatible with the market’ with limited consideration for holistic benefits for the community itself (Kumar et al., 2021: 6). In other words, the combination of limited practical research on the impact of agrivoltaics installations over time in an Indian context with a lack of specific regulation for agrivoltaics implementation processes influence the configuration of the system as one that prioritises overall economic productivity. While this is only one case where an agrivoltaics configuration has prioritised energy generation over agricultural cultivation, it represents a precedent that places agrivoltaics installations within conversations of productive land versus wasted land, which is where many large-scale solar developments sit in India (Baka, 2017). This outcome or similar remain uncertain, however including agrivoltaics within existing dichotomous discussions of productive and wasted land limits its innovative and flexible potential within numerous contexts and may, in turn, result in further exclusion and dispossession of communities that cannot participate in its transition due to lack of regulation, accessible and accurate knowledge, and financial assistance.

Despite these potential implications and in contrast to the pre-established concerns impacting agrivoltaics acceptability (see Chapter 6), the Delhi farmers had a relatively high acceptability pre-adoption. However, this acceptance may be attributed to the opportunities presented by the promising financial security an agrivoltaics dual-income configuration could provide them. As briefly introduced above, concerns regarding farmer agency throughout the development process appear to have been addressed in this case. Solar developers approached the Delhi farmers to lease their land for the development while still being able to cultivate, had assistance from their local KVK, and were encouraged to participate in the design of the system (AVS 1, 2023). However, by providing the farmers with significant control over how the system was configured combined with limited information available to them, and with the knowledge that maximising electricity generation would provide significant financial security, the Delhi farmers have implemented a less agriculturally productive system.

Three years post-adoption, the farmers have since recognised the slight 'damage' to their agricultural output due to the reduced sunlight and have begun to consider the panels as 'encroaching' on their land despite the financial benefits (AVS 1, 2023). This further emphasises the importance of improved access to accurate contextual information on how the technology impacts farmland, including best practices for system configuration. The lack of readily available information for adopters fosters a culture of 'learning by doing' among farmers (KVK Delhi, 2023). However, as one progressive farmer championing agrivoltaics capacity building opportunities emphasises, such learning by doing cannot be 'left [only] to the farmer' and an open exchange of knowledge about best practices would produce the most effective, efficient system (AVS 2, 2024).

As a result of their experiences with their installations close configuration, however, the Delhi farmers have since developed a more complicated perception of agrivoltaics post-adoption. The allowance for agency without full access to the knowledge, whether due to a lack of knowledge exchange or a limited availability of relevant research, produces both justices and injustices as the farmers' livelihoods and the surrounding agricultural communities are impacted in new and different ways. A solar pump farmer recognised that a farmer's 'land [will] be encroached upon' if they were to install agrivoltaics (SP 1, 2023). The Delhi farmers now consider the same, as they have observed implications for their agricultural productivity resulting from their agrivoltaics installation (AVS 1, 2023).

Alternatively, an additional sense of agency and ownership has been generated through agrivoltaics. Despite concerns over land competition, the Delhi farmers have now been able to focus entirely on agriculture, albeit dual-use agriculture with overhead solar, and have been provided an opportunity to diversify their income through electricity generation rather than alternative manual labour work (AVS 1, 2023; KVK Delhi, 2023). Despite the changes to the agricultural production, the farmers now have the space to experiment and adapt to the new configuration, whereas before they were obligated to seek additional, unrelated, and difficult work. In other words, the agrivoltaics system has allowed for the farmers' agricultural focus to be restored. While they still may have 'one foot' in a non-agricultural sector (Lerche, 2021: 1388), in this case of renewable energy generation, there is more overlap and thus more time for their chosen livelihood or considering alternatives and further adaptations.

Despite challenges with the system, they explained that they would still choose to install the system in the first instance (AVS 1, 2023). When asked if there was an aspect they would like to change, the Delhi farmers mentioned an interest in transparent panels, so they could improve their cultivation productivity through increase sunlight penetration while maintaining the same number of panels (AVS 1, 2023). Similarly, solar pump farmers recognised that cultivating crops underneath panels was a 'good idea' (SP 2, 2023).

> The solar pump does usually fulfil irrigation needs, but doesn't always, so I would wish to make some changes to the panels […] The panel should be higher. Look, the land is so shady underneath. This land is waste. Let's assume this to be approximately two and a half hundred yards of wasteland. But if the panel is high, there should be farming below it (SP 2, 2023).

This highlights a growing knowledge of solar energy innovations and a potential increased interest in future participation in the renewable energy transition. This farmer's perception of 'wasted' land is also notable in this instance. Whereas developers and policymakers are understood to consider unused land 'unproductive' or 'wasteland' as a justification for development (Baka, 2020; Hu, 2023), this participant considers the underutilised land underneath his solar panels as an opportunity to plant more crops. While there are some similarities between these perspectives on wasted land, specifically pertaining to perceptions of underutilised space and its potential, this participant is only considering land underneath his solar panels as having this potential. In other words, the land beneath solar panels in development discourse would not be considered 'wasted' because productivity was already addressed through the installation of solar, whereas this farmer sees additional potential in these spaces. This notable consideration for integrating agrivoltaics components, i.e. cultivating underneath traditional, ground-mounted panels, illustrates farmer ingenuity and the importance of elevating their knowledge to adapt agrivoltaics to new contexts as it is evident they are already assessing ways to upgrade their existing, small-scale solar.

However, in contrast to this, the agrivoltaics farmers also acknowledged that they were unsure if they would continue with solar energy following the completion of their 25-year lease with the developers, which they felt was too long for solar to be 'encroaching' on their land (AVS 1, 2023). Although the farmers have received additional income from the solar panels, their growing perception of agrivoltaics encroachment has begun to impact future acceptance. While this case underscores the notion that many Indian farmers and other stakeholders at multiple levels view agrivoltaics as an avenue for economic development and securitisation through the ability to sell excess electricity to supplement and diversify their income (AVS 1, 2023; AVS Developer, 2024), a growing reluctance for future development remains.

Land conflict has long been cited as a justification for agrivoltaics, as both climate impacts and large-scale ground-mounted solar installations exacerbate uncertainties in the agricultural sector (Pascaris et al., 2021; Schindele, 2021b; Widmer et al., 2024). Likewise, concerns over land competition because of agrivoltaics without robust regulation preventing the prioritisation of energy generation at the expense of agricultural production have been raised (Torma & Aschemann-Witzel, 2023; Worringham, 2021). However, these concerns have only been raised in pre-installation scenarios in existing literature and not yet observed in installations post-installation, as in the perceived land 'encroachment' for the Delhi farmers. Thus, the concerns over land encroachment by solar pump farmers contemplating agrivoltaics and the agrivoltaics farmers in Delhi post-adoption are important to highlight here. While the Delhi farmers are still accepting of the technology post-adoption due to the economic security it has provided them through their ability to sell excess electricity to the grid, their perceptions have evolved to echo concerns over land encroachment.

> There are advantages of applying it. The village is full of electricity, but we did used to suffer because we couldn't afford it. We didn't have that much money. We used to only produce one crop a year but now our mustard plant has a double yield.
>
> […]
>
> The new technology that is available on other sites had copied the gap [between the panels] from KVK [Delhi]. There is more a gap […] in the middle. That means that farming and produce, of big greens and vegetables, poha, whatever, can be done there [in the sunlight] […] and basically cultivation under the shade has not happened much (AVS 1, 2023).

Despite recognising the benefits of improved energy security and expressing interest in new innovations to solar panels, such as semi-transparent, these farmers still acknowledged the implications of agrivoltaics on their land because of their close panel configuration affecting sunlight penetration (AVS 1, 2023). Additionally, due to these impacts, they were undecided whether they would choose to re-install an agrivoltaics system at the conclusion of their 25-year lease period, simply due to the length of time the solar panels will be encroaching on their land (AVS 1, 2023). These factors illustrate the emerging and evolving reluctance current agrivoltaics farmers are experiencing, as they consider the system as one to live alongside or tolerate, as they experience both the benefits as well as the drawbacks. This nuance within social acceptance emphasises the grey areas between the binary of acceptance and rejection. In this case, the AVS 1 farmers were presented a choice to install agrivoltaics on their land. However, the choice between energy poverty and limited income from agriculture that necessitated seeking out additional, manual labour work and installing agrivoltaics despite the limited information available to them, it was not much of a choice at all (Liebe & Dobers, 2018; Pidgeon & Demski, 2012). Thus, these farmers may not be enthusiastic about their agrivoltaics system overall, however rather than discounting their experience as attempting to fit them into an acceptance/rejection dichotomy, it is crucial to understand the spectrum of nuanced emotional responses and/or socio-cultural contexts that influence decision-making.

The proliferation of agrivoltaics installations will produce more nuanced perceptions of the technology, and the growing reluctance among Indian farmers to initiate or continue participation in agrivoltaics is notable. The trust within agricultural communities outweighs the trust individual farmers have for developers, researchers, and other elite stakeholders, and thus overall social perceptions of agrivoltaics may stagnate because of relatively few, not ideal experiences with the technology are shared along these trusted networks (Alexandre et al., 2018). The farmers in this case were aware of what the agrivoltaics system would look like and the opportunities it could provide but were not aware of the long-term implications of leasing their farmland for the lengthy 25-year period. This difference has thus in turn influenced their perceptions of the technology in general.

7.2.2. *Knowledge Exchange and Co-Production Opportunities (or Lack Thereof)*

It has been suggested in this thesis that there are challenges associated with the availability of accurate information for farmers regarding agrivoltaics and its impacts, which in turn influence social acceptability (see Chapter 6). While this can be attributed to limited but growing research in India, there is also a limited integration of farmer knowledge and practical research within emerging literature, regulations under development, and existing developments that might make agrivoltaics more 'inclusive' (Melnyk & Singh, 2021: 50; Pulipaka et al., 2023). In essence, farmers are not comprehending the full picture of agrivoltaics. For example, while there is no specific policy for agrivoltaics in India, it is stipulated that no groundwater irrigation can occur with agrivoltaics systems (KVK Delhi, 2023). While developers and farmers are aware of this fact and have mitigated it by including a rainwater harvesting gutter system at the Delhi agrivoltaics site, the increasingly unpredictable weather patterns combined with an inability to access groundwater has resulted in the Delhi farmers having to purchase exterior freshwater tanks to irrigate (AVS 1, 2023). This represents an additional cost medium, small, and marginal-scale farmers encounter after installing agrivoltaics. While this cost may not determine whether they proceed with adoption, as the prospect of energy or financial security may weigh higher in their regard, prior knowledge of it as a possibility would have been beneficial.

In practice, this additional, unexpected expense was also recognised as a difficult change by the Delhi farmers especially in the context of increasing climate uncertainties, including droughts, that might contribute to uncertain prices of freshwater (AVS 1, 2023). Wallsgrove et.al., (2022) characterises restorative energy justice as the concurrent recognition of and attention to addressing harms inflicted by energy development. In comparison, agrivoltaics represent a potential holistic, regenerative alternative to traditional ground-mounted solar and is theorised to address concerns that may lead to harms, such as uncertain costs for resources such as water or energy, and unreliable agriculture pricing that might incentivise seeking out additional work (Elevitch et al., 2018; Meitzner et al., 2021). However, despite restoring the Delhi farmers to their 'original state' as agricultural producers without needing to take on additional laborious work, while providing resource security and improved agency in the process, the agrivoltaics installation has introduced new uncertainties, if not necessarily harms, that will need to be recognised and addressed in future agrivoltaics discussions (Hazrati & Heffron, 2021: 4; Wallsgrove et al., 2022).

Similarly, local utilities or discoms have specific thresholds as to how much electricity they can purchase from renewable sources such as decentralised, feed-in solar systems, which limits the accessibility of agrivoltaics, especially if the central driver for its installation is the prospect of a dual income (Government of India, 2019a). As stipulated by the PM-KUSUM policy documentation, Discom energy purchase thresholds are capped at 2.5 MW (Government of India, 2019a). This is notable because by the Delhi farmers selling almost all the energy produced by their 2.5 MW agrivoltaics system (AVS 1, 2023), they have essentially cornered the market in their community and have prevented any other potentially interested farmer from adopting the system in a similar manner. The Delhi farmers may have achieved a degree of restorative justice from the installation of their agrivoltaics system through improved agency and resource security but have simultaneously generated distributive injustices for other local farmers. By installing a system and selling back electricity that meets their local discom's feed-in threshold, they have consequently prevented any other farmers from connecting any potential agrivoltaics system to the grid, which has been observed as a significant motivator by participants (AVS 1, 2023; AVS 2, 2024) and in other literature (Pascaris, et al., 2022; Mahto et al. 2021). While other farmers in the region can install agrivoltaics is they incur additional, significant costs to upgrade the grid (Government of India, 2019b) or install decentralised agrivoltaics systems if they are interested, the lack of financial assistance for adoption and lifetime maintenance combined with the inability to contribute to a dual-income stream, decentralised configurations of agrivoltaics are inaccessible and impractical as current policy stands.

The introduction of agrivoltaics as an opportunity for farmer welfare, such as in the PM-KUSUM documentation, is therefore misleading because of the limited information available to farmers in reference to capabilities necessary to implement and maintain the system. The Krishi Vigyan Kendras (KVKs), or semi-governmental farmer extension research and support centres across India, are excellent resources for farmers interested in improving their productivity and sustainability. The Delhi KVK has been and continues to be an excellent resource for agrivoltaics, as it possesses one of the 16 agrivoltaics pilot sites commissioned by the central government (Image 2). The purpose of this 0.5 kW site is to contribute to ongoing research on agrivoltaics in an Indian context but also teach local farmers about the technology and encourage further adoption (KVK Delhi, 2023). KVKs are widely recognised as extremely beneficial and important sources of knowledge and training opportunities for new and/or sustainable agricultural practices (NGO 1, 2023; SP 1, 2023). However, there exist significant issues with demonstrating the benefits of agrivoltaics to local farmers who are interested in the economic opportunities of such a system but would not be able to take advantage of it due to the caps set by discoms.

The participant from the Delhi KVK stated that their main 'objective' is to 'provide this technology to more and more people, so that farmers can make the decision for themselves', but the participants acknowledge that there 'really should be more data' (KVK Delhi, 2023). While the KVK staff do offer training sessions for local farmers to learn about agrivoltaics, they can only speak on their personal experience at the KVK centre and equally rely on farmers' experiences to inform their own adaptations to their agrivoltaics structure (AVS 2, 2024). Introducing such a new technology, combined with limited research to inform sustainable and effective installations applicable to the small-scale farmers that seek training with KVKs, will require significant levels of collaboration between farmers and local educational and research institutions, such as KVKs. While the Delhi farmers have experienced some drawbacks from their agrivoltaics system, their experience has been relayed to the staff at the KVK to further inform their own research and adaptation strategies on their own system, and vice versa. For example, while the Delhi farmers opted to prioritise energy production and install a tight configuration of solar panels, the KVK staff were able to provide advice on the best crops to cultivate under that much shade (turmeric). In turn, the KVK staff was able to confirm that a tight agrivoltaics configuration is not as effective for agricultural production as a more widely spaced configuration, which will be helpful for any future installations (KVK Delhi, 2023). The importance of knowledge co-production has been well-documented in agrivoltaics literature (Trommsdorff, Dhal, et al., 2022; Widmer et al., 2024); however, the same pool of literature highlights the need for further study in different climate conditions to 'generalise the trends', including those beyond modelling scenarios and feasibility studies (Ketzer et al., 2020: 7). Thus, this confirmation and degree of experiential knowledge exchange is an important contribution toward developing an understanding of agrivoltaics configurations, especially in a rural Indian context.

A landowning farmer outside of Mumbai in the state of Maharashtra acknowledged the gap in both research and practical experience with agrivoltaics in India. This farmer has installed 10 MW of solar on his agricultural land, all with an agroforestry component, but with an intention to upgrade the entirety to agrivoltaics over the coming years (AVS 2, 2024). I met this farmer by chance after presenting on preliminary findings at a research conference in Summer 2024, and thus our conversation was unstructured. However, the importance of this farmer's excitement and interest in agrivoltaics as a potential component of India's sustainable energy transition cannot be understated, as he represents an independent, medium landholding farmer perspective passionate about agrivoltaics and driven by moral responsibility to encourage further development. To this participant, he felt he 'had to do it [install agrivoltaics]' because he had the resources, including land and experience working as a farmer, but also has worked for his local discom and agricultural university and thus understood the proper processes and development channels (AVS 2, 2024). Ultimately, he believed he had the capacity to experiment with the technology, contribute to capacity building and training opportunities for other interested farmers, and provide renewable energy to surrounding villages by selling the electricity produced to the grid.

This Maharashtra farmer's driving force for installing agrivoltaics has already been discussed in the previous chapter (Chapter 6), however his experience with the system is more positive due to his experiential knowledge as both a farmer and energy distributor. A former employee of both the Maharashtra Agricultural University and his local utility, this farmer utilised his experience to design and install an agrivoltaics system on his family farmland outside of Mumbai. In addition to feeling as if he 'had to do it' simply because he had the experience, land, and financial capacity to do so, his optimism about his installation and about the future of agrivoltaics in India ('it's so exciting back home') has already attracted local KVKs requesting that he give tutorials to local farmers (AVS 2, 2024). This farmer's case is notable because he represents a source of local farmer knowledge integrating agrivoltaics into an existing solar system as well as designing a new installation. His insights into the independent financing procedures indicate a complex, and potentially predatory process (AVS 2, 2024). But despite this, his enthusiasm for agrivoltaics as a climate mitigation strategy and passion for educating other farmers illustrates the potential for a more community-forward and collaborative future for agrivoltaics that goes beyond the neoliberal, market-forward approach for the solar industry in India today (Kumar et al., 2021; Singh, 2024).

It is evident that the existing agrivoltaics sites in the Delhi greenbelt highlight the importance of treating farmers as equal stakeholders throughout the decision-making process, including during research production to inform that decision-making. The Maharashtra farmer's experience strengthens this argument through the enthusiastic exchange of knowledge with his local KVKs and communities. In turn, his efforts emphasise the importance of knowledge co-production when further developing innovations like agrivoltaics.

Despite opportunities for such collaborative processes, however, challenges remain for the continuing implementation of agrivoltaics in areas where systems already exist. The Delhi agrivoltaics farmers integrated the system due to the opportunities it has provided them and while these opportunities are notable and concrete, they are also more aware of the challenges associated with solar technology on their agricultural land than beforehand. Their experience, in conjunction with the Maharashtra agrivoltaics farmer, underscores the spectrum of social acceptance across the different phases of adoption. Compared to the solar pump farmers, sceptical of agrivoltaics based on potential land competition fears, the Delhi farmers had a high level of acceptability and willingness to adopt the technology. Their acceptance may be attributed to the pretence of a choice available to them when agricultural cultivation is not a lucrative enough livelihood on its own. However, as inferred from their nonchalant tone and body language during our walking interviews, the Delhi farmers' relatively tolerant acceptance of agrivoltaics on their land despite this context is an interesting contribution to the wider social acceptance of agrivoltaics scholarship.

While the Delhi farmers' experiential knowledge is and will continue to be important for informing future configurations of agrivoltaics, as the KVK Delhi staff emphasise (2023), there is still an increasing need for more research. There is a need for facilitating more early adopters while also generating an enabling environment that would allow them to do so. The Delhi farmers are early adopters of agrivoltaics and have even employed a collaborative model that represents a novel agrivoltaics configuration and an opportunity for small farmers to engage with the technology.

However, despite this potential, as exemplified by the Maharashtra farmers' experience, the agrivoltaics systems in both the Delhi and Maharashtra case reflect existing models of solar development that are dependent on developer relationships and potentially exploitative financing schemes (NGO 1, 2023; AVS 2, 2024). Further, due to the limiting capacity of discom feed-in energy caps, land competition fears, and limited opportunities for knowledge exchange, there will need to be further allowance for adaptions, or even disruption, to the existing model of agrivoltaics implementation.

The following section will present an example of disruption to the current agrivoltaics development paradigm in India. In what will be introduced as the Hybrid Case, one solar pump farmer has received financial subsidies from existing policies for his decentralised solar installation and subsequently has integrated agrivoltaics components. His efforts not only represent the experimental nature of Indian farmers but also a potential roadmap for future innovative agrivoltaics configurations that are more accessible to the wider agricultural community.

7.3. The Hybrid System: A Case Study of Decentralised Agrivoltaics

Agrivoltaics are conceptualised as an innovation rooted in agroforestry that combines restorative agriculture and solar energy to achieve a highly efficient use of land (Elevitch et al., 2018; Mahto et al., 2021). The technology is discussed and analysed in relevant literature through feasibility studies and models (Giudice et al., 2021; Trommsdorff, Dhal, et al., 2022), but it is rarely considered an option to convert an existing solar system. Generally, if the panels are installed traditionally, or lower to the ground, and do 'not allow for any operation underneath' then they are not considered agrivoltaics or have the potential to become agrivoltaics (NGO 2, 2023). However, this perception is one that is influenced by the existing, incumbent understandings of what an agrivoltaics system can look like (Amaducci et al., 2018; Chandra Giri & Chandra Mohanty, 2022). To render the technology more transferable, such as in new contexts where farmers do not have access to same financial capital, subsidisation schemes, or regulations to prevent exploitation, it is imperative that the definition of agrivoltaics can be expanded. Namely, if the installation involves and allows for innovation, experimentation, and adaptation, then the understanding of agrivoltaics and just who has a say in what these systems look like can be expanded to become more accessible and equitable. This section will introduce one such case wherein an off-grid, decentralised Indian farmer in Haryana has utilised existing institutional structures to install solar energy on their land and simultaneously include agrivoltaics components through their own volition and based on their experiential knowledge as a lifelong farmer.

In one Haryana village, a state to the northwest of Delhi, electricity infrastructure is more unreliable and sporadic. The son of one generational farming family gave me a tour of his solar irrigation pumps, solar panels, reservoir, and expansive orchards (see Images 6-8). He and his uncle both received individual subsidies to install their two solar pumps under separate names to receive double subsidies, or one subsidy per solar pump system (Hybrid Case, 2023). As an entirely off-grid farm, they justified this ownership model to maximise their solar generation potential to facilitate easier irrigation and electrify their home.

'Really, we wanted the electricity. But we accepted the water [security] as well'.

[…]

'We didn't really face any challenges. We had what we needed [with the diesel pump] but wanted more' (Hybrid Case 2023).

 

[Image 6 (top): Six solar arrays next to open-air reservoir fed by the solar-powered irrigation pumps, Hybrid Case (Author’s Own, 2023)]

[Image 7 (bottom right): A small beekeeping box underneath one of the solar arrays next to the reservoir and orchards, Hybrid Case (Author’s Own, 2023)]

[Image 8 (bottom left): A view of the lime orchards adjacent to the solar arrays and beekeeping, Hybrid Case (Author’s Own, 2023).

In contrast to the Delhi farmers who were driven by the financial security and the Maharashtra farmer who felt a moral responsibility to install agrivoltaics, the farmers in this Hybrid Case chose to install solar pumps in line with academic consensus for agrivoltaics adoption: energy security and electricity access (Barron-Gafford et al., 2019; Kumar et al., 2024; Pascaris et al., 2022; Randle-Boggis et al., 2021). This Haryana farmer has expressed their contentment and can now ‘manage’ with their two solar pumps (Hybrid Case, 2023). While their ability to manage with the combined solar and diesel irrigation pumps, compounded with the newfound electricity security, is indicative of the lack of issues faced during the decision-making process, it also reflects the spectrum of acceptance post-adoption. The promise of energy security where before they had limited access initially incentivised their adoption of solar energy on their land, but ultimately it was the associated benefit of water security that has improved their acceptance of the system overall. The farmers in this Hybrid Case were driven to install solar pumps on their land to improve access to water and electricity and increase agricultural productivity. However, as will be discussed in the following sections, they have upgraded these systems to integrate solar energy more fully into their cultivation practices, effectively designing an agrivoltaics system without experiencing the complex implementation process.

However, in an arid, northwestern state that experiences increasing incidences of climate and monsoon variability, upon which many farmers rely to irrigate or refill aquifers, and rising temperatures, groundwater accessibility and reliability will be impacted (Galan, 2022; Mahto et al., 2021).

> '[The groundwater] is at ground level when it rains. And maximum depth is at 7 to 8 feet. Although the groundwater here is saline water' (Hybrid Case, 2023).

When compared to the other solar pump farmer participants in rural Haryana where their borewells go as deep as 160 metres or more (SP 1 and SP 2), groundwater is more accessible for the farmers in the Hybrid Case. However, this participant has noted that he and his family are experiencing saltwater intrusion in their borewells (Hybrid Case, 2023). This can be attributed to the overexploitation of groundwater resources over time (NGO 1, 2023), which may not necessarily be due to these farmer's cultivation practices since this participant mentioned he did not leave the solar pumps open continuously, as some solar pump farmers are known to do (Hybrid Case, 2023; NGO 1, 2023; KVK Haryana, 2023). Instead, this salinisation can be a result of decades of over-pumping within the Green Revolution state, which has reduced pressure in the aquifer over time (Khara & Ghuman, 2023; KVK Haryana, 2023). While it was not apparent that the Hybrid Case farmers were experiencing significant issues with their water quality yet, they have noticed their water is salinized and in so doing, recognised that it will eventually affect their crop production and soil health (Hybrid Case, 2023).

Considering this emerging concern over water resources, the Hybrid Case participant's efforts at experimentation with his solar pump practices, including his efforts to maximise water efficiency through dual use of land, are significant and have potential to inform further adaptive for the sustainable integration of solar energy in rural India, such as regenerative or innovative agrivoltaics practices. After all, 'necessity is the mother of invention' (NGO 2, 2023). These efforts will be elaborated on in the following sections.

7.3.1. Agrivoltaics Integration Strategies

Due to both this recognition of necessary future adaptation and his own ingenuity, the Hybrid Case farmer has begun to integrate agrivoltaics components within his solar energy system Hybrid Case, 2023). While the panels in his system are low to the ground in a traditional solar configuration, this participant has recognised the importance and the potential of using the available space below the panels. By placing beekeeping boxes in the panels next to his citrus fruit orchards (see Image 7), he has maximised formerly unused space while also boosting pollination, protecting the bee boxes from the sun, and benefiting from honey production for personal use (Hybrid Case, 2023). When asked about why he chose to start keeping bees under his panels, he gave a more flippant response: 'We [just] tried it like that' (Hybrid Case, 2023). Such a response emphasises the farmer's flexibility and willingness to experiment with new adaptations or innovative approaches to their solar pump, indicating an interest in future adaptation to the system if it improved efficiency and effectiveness. This participant recognised that this was only a small adaptation but expressed that he was pleased with the small positive impact this change has had (Hybrid Case, 2023).

This experimentation is further exemplified by the Hybrid Case farmer's agricultural efforts to cultivate spinach directly underneath the low-to-the-ground solar panels in the drier winter months (Hybrid Case, 2023). Due to the irregularity of the monsoon just before and at the time of my field visit in September 2023 (Jadhav, 2023), he had planted the spinach earlier than planned to take advantage of the more arid weather conditions earlier in the year. Planting the spinach under the panels is not only an efficient use of land but also maximises water efficiency. The shade provided by the low panels is well-suited to low, shade-tolerant plants like spinach, but it also allows for increased water retention in the soil, reducing the irrigation requirements for the crop (Amaducci et al., 2018; Marrou et al., 2013). In this case, where the farmers are experiencing groundwater salination, the reduction of water requirements for some crops allows for more efficient use of resources and perhaps even reduced need for pumping in the long-term.

Further, successfully utilising the land underneath the low-positioned panels illustrates that some concerns over land competition from agrivoltaics may be undeserved, or at least require further critical engagement, among the farming communities. While the Delhi farmers considered their agrivoltaics system as an encroachment despite its relative success, the use of the space underneath the low-lying panels in the Hybrid Case exemplifies the fact that there is not one singular method of integrating agrivoltaics. Recognising that taller crops such as turmeric could not be grown underneath traditional panels, the Hybrid Case farmer instead planted another shade-tolerant crop (spinach) and installed beekeeping boxes to boost citrus production in neighbouring fields. The Hybrid Case farmer's strategy does not necessarily involve crop production directly underneath the solar panels, which is a widely recognised defining feature of agrivoltaics (Barron-Gafford et al., 2019; Gomez-Casanovas et al., 2023). Instead, it utilises the available space to assist crop production through encouraging pollination. While this participant's beekeeping plays only a small role in his cultivation practices, his efforts highlight the importance of allowing for flexibility within agrivoltaics configurations and the concomitant widening of definitions for agrivoltaics. Innovation is a dynamic process that requires adaptation when implemented in new contexts, such as decentralised or small-scale agriculture (Glover er al., 2019). Opportunities for flexibility in agrivoltaics conceptualisation represent the importance of considering the range of possibilities in other regional, climatic, and sociocultural contexts as well as how definitions can evolve depending on these new contexts. Thus, as exemplified by this case, the innovative potential of agrivoltaics lies in its symbiotic potential, but also the ways in which it can be adapted to new environments, scales, and purposes by Indian farmers in 'unexpected' ways (Liu et al., 2020: 315).

In addition to the innovative strategies used in this Hybrid Case, the farmer has made strides to adapt to the changing climate in northern India. The increased variability of monsoon upon which many Indian farmers, including this participant, rely to replenish water resources, including wells and groundwater aquifers, has resulted in the driest August and early September since 2018 (Jadhav, 2023). In recognition of the unreliable rainfall, this participant has initiated mushroom cultivation both under open air and underneath one of his solar panels because 'no irrigation [is] needed' while his turmeric crop would be 'useless' without irrigation (Hybrid Case, 2023). There a minimal irrigation requirement for a mushroom crop, and mushrooms have been observed (Grimm & Wösten, 2018; Holt et al., 2024) as contributing to soil health through natural fertilisation processes. Thus, this farmer is contributing to important soil turnover through his mushroom crop, and by utilising the available, shaded space underneath his solar panels, he is taking advantage of a cool, more humid ecosystem ideal for the crop's production. Similar to his beekeeping efforts, this integration of mushroom crop underneath his solar panels is miniscule compared to the 45 acres of farmland he owns. However, it is evident that this participant is taking not unsignificant steps toward improving his overall water efficiency, crop productivity, and soil health. Even if only spinach, or other low-lying crop, is planted in the soil fertilised by mushroom cultivation, this participant is still contributing to that crop's improved health and growth. Nevertheless, despite its potential, mushroom cultivation underneath solar panels have not been heavily studied in agrivoltaics literature (El Kolaly et al., 2020; Rukhiran et al., 2023; Tajima & Iida, 2021).

The increasing concern over ground- and freshwater accessibility as expressed by each of the solar pump farmers interviewed in Haryana and the Delhi farmers, respectively, may be mitigated by the integration of alternative strategies. These strategies include the freedom to experiment to adapt and evolve existing solar systems, such as the use of water and land efficient crops like mushrooms, in addition to the previously stated requirements for 'reasonable' (AVS 2, 2024) financial support, capacity building, and knowledge co-production opportunities to facilitate holistic agrivoltaics implementation.

While the ability of the farmer in the Hybrid Case to be flexible might be determinant on the presence of existing knowledge as a generational farmer and agronomy student, or more stable resources as an owner of a large 45-acre family farm, he is nevertheless 're-configuring' an existing technology to address a 'network [or institutional] weakness', or gap, in current decentralised solar and agrivoltaics installation strategies (Jacobsson & Bergek, 2011:48). Such weaknesses in this case refer to the incumbent development strategies for agrivoltaics that reflect and perpetuate existing solar implementation strategies that exclude small and marginal-scale farmers due to a lack of financial and regulatory support, and decentralised farmers due to an inability to reap benefits of a dual-income through grid feed-in tariffs. This Hybrid Case exemplifies only small changes made to a relatively small solar system, however despite not experiencing financial benefits a grid-connection would provide and reiterating concerns with the land lease period, this participant acknowledged experiencing benefits noted in agrivoltaics literature, including improved water efficiency.

> This is a good system. [Although] the subsidy period should be from five years to 10 years instead of the 25 years […but] we have 45 to 50 acres that we are irrigating with the help of our two solar pumps […] so we can manage with that.
>
> […]
>
> While there is no irrigation needed for our mushroom cultivation [under the panels], turmeric cultivation would be useless without irrigation from the pump (Hybrid Case, 2023).

Further benefits mentioned include improved energy security in the home and for farming practices, reduced cost for traditional fuel sources like diesel, efficient use of space underneath panels to improve quality of crops both underneath and adjacent to the system, and improved solar panel efficiency thanks to the cooler microclimate provided by the crops underneath (Hybrid Case, 2023; Barron-Gafford et al., 2019; Verheijen & Bastos, 2023; Williams et al., 2023). This participant's experience highlights the potential for alternative configurations and conceptualisations of agrivoltaics, allowing for farmers who already possess ground-mounted solar to adapt their installation and participate in the transition toward more regenerative practices, rather than assuming that agrivoltaics should present or be implemented in a specific manner.

As previously discussed, solar irrigation pumps are an already socially accepted technology in India with an anticipated nationally funded subsidy. Farmers are motivated by increased water security during increasingly unreliable climate conditions and the provision of 'free' and decentralised solar energy (NGO 1, 2023; KVK Haryana, 2023). While subsidisation under the Scheme was introduced to facilitate accessibility, the use of substandard materials and neglected infrastructure (AVS Developer, 2024), and the lack of sufficient support for agrivoltaics, combined with the Scheme's implementation issues, renders the technology inaccessible and delegitimises it to most Indian farmers (National Researcher, 2023; Alexandre et al, 2018). These systemic weaknesses ultimately prevent farmers from experimenting with decentralised solar and agrivoltaics innovations in a new context. Thus, while the Hybrid Case farmer is self-identified as a progressive farmer—as an owner of a larger, generational farm—his efforts are at the forefront of decentralised agrivoltaics experimentation from which further research could glean significant insights into the future role of the technology in global energy transitions. Whether because he was unable to install a traditional agrivoltaics system due to lack of regulation and financial assistance, or uninterested in another solar installation in addition to his farm's two solar pumps, this participant only noted they 'can manage with' their farm's current configuration (Hybrid Case, 2023). Instead of considering another installation, he combined both his knowledge as a rural farmer with his experience of his two solar pumps to produce an innovative and more accessible example of agrivoltaics in a new context. He has shown that there are alternative strategies for integrating agrivoltaics if farmers themselves have the agency and capacity to experiment. In other words, if the farmers are treated as an equal stakeholder within agrivoltaics policymaking and knowledge production, and the definition of agrivoltaics itself is allowed to evolve with each new context, then the technology itself may become more accessible and acceptable to previously excluded communities in this transition.

The current policy landscape for agrivoltaics is prohibitive for many farmers in India, as exemplified by perfunctory mention of agrivoltaics in existing policy documentation and lacks specific regulation (see Chapter 4 for more details). However, this Hybrid Case of innovative solar pump-cum-agrivoltaics configuration may point to an alternative, and potentially disruptive, strategy for fostering rural, decentralised, and formerly excluded farmer participation in the agrivoltaics transition through the integration of agrivoltaics components into existing subsidised solar installations.

7.4. Agrivoltaics for Whom? Innovative Configurations, Restorative Justice, and Future Pathways for Agrivoltaics

Disruptive innovation is related to the conceptualisation of acceptability and acceptance. A disruptive technology—a technology that is both new and challenges the extant 'incumbent' technology, or status quo—may have lower acceptability in relation to its ultimate social acceptance after individuals and social groups who have used the innovation can vouch for its benefits (Si et al., 2020; Si & Chen, 2020). Disruptive innovation requires not only word-of-mouth support for a nascent technology within and between community groups and stakeholder levels (Upham et al., 2015) to encourage social acceptance, but also an allowance for flexibility and experimentation provided by improved trust between stakeholder groups, such as key decisionmakers, regulatory bodies, and the farming community (Alexandre et al., 2018b; Liu et al., 2020). Ultimately, the recognition of adaptations and experiments undertaken by local communities and farmers by researchers and decisionmakers reduces 'tunnel vision' within transitions but also encourages 'creative low-tech solutions' that integrate local knowledge, values, and narratives (Melnyk & Singh, 2021: 49). This treatment of farmers as equal stakeholders in the innovation process provides a sense of recognitional justice that in turn engenders a growing sense of trust between stakeholders (Goedkoop & Devine-Wright, 2016) and may encourage further social acceptance of technologies. This cycle of trust and experimentation must begin somewhere, and in the case of agrivoltaics in India, it may just start with the integration of agrivoltaics in existing systems by individual farmers that will in turn encourage the elevation of farmers to an equal stakeholder position, bolstering both trust and opportunities for further adaptations.

However, despite this optimism and in reference to policy documentation globally, agrivoltaics have specific definitions that are designed to ensure that regulations are followed, and that neither energy nor agricultural production are affected by the other (Worringham, 2021). The existence of such definitions in policy documents is crucial to protect agricultural lands from exploitation of the renewable energy transition, yet the pervasiveness of these definitions have the potential to hinder innovation, especially when adapting the technology to new scales and contexts.

> They [rural farmers in Eastern India] thought it was agrivoltaics because it [their solar pump] helped agriculture, right? But no. Installing solar panels and pumping water to irrigate crops is not agrivoltaics. Agrivoltaics means you have to combine the crops with solar together (NGO 2, 2023).

While this participant accurately refers to the established conceptualisation of agrivoltaics, such strict adherence to the accepted definition of the technology challenges just who is responsible for defining agrivoltaics in novel contexts, and whether that incumbent understanding helps or hinders acceptance and uptake. This participant is critiquing solar pump farmers, stating that the solar pumps alone cannot be considered agrivoltaics simply due to their proximity to agricultural land. While this may be true on its surface, with most Indian farmers classified as small or marginal, who generally employ hand cultivation, the reality is more complex. In these scenarios, the traditional design of agrivoltaics wherein panels are raised high enough for machinery to be used underneath on larger land parcels may not be feasible or necessary. Thus, it is important to consider that agrivoltaics, including both its existing conceptualisations and configurations, will need to be adapted to become more accessible in different contexts, including rural and decentralised regions in India.

A growing academic opinion further emphasises that definitions should be more flexible to account for the adaptations individual farmers have the potential and ingenuity to accomplish (Trommsdorff et al., 2023). In examples such as the Hybrid Case, a shift away from the established norm toward alternative agrivoltaics configurations through experimentation efforts is being observed. The Hybrid Case farmer's utilisation of available space underneath the solar panels that power his irrigation pumps to directly cultivate low-lying crops such as spinach and mushrooms as well as engage in secondary cultivation through beekeeping for pollination exemplifies an alternative, and more accessible, method of Indian farmers benefitting from agrivoltaics' benefits. This participant's innovative strategies also exemplify how agrivoltaics can be integrated into existing, decentralised solar installations and thus represent a new form of ownership that fosters improved farmer agency and thus care for the innovation (Kumar et al., 2021). It is in this way that this case represents a potential future for agrivoltaics that goes beyond market structures to encourage local participation in the energy transition.

In fact, the experience of the Hybrid Case farmer illustrates the disruptive potential of Indian farmers if allowed to experiment. In recognition of the limited 'reasonable' financial assistance, policy and regulatory protections, as well as integration of farmers' perspectives within agrivoltaics discussions at the national level, this participant has utilised an existing, socially accepted technology (the solar pump) and policy to receive a 75% subsidy (Hybrid Case, 2023) for each pump and integrate agrivoltaics accordingly. While his motivating factor may have been to install solar pumps to improve electricity and water security for his family farm, this participant was nevertheless driven to integrate other features into his configuration that facilitates land and agricultural efficiency. In doing so, he has also highlighted an alternative agrivoltaics ownership practice that is accessible to rural, decentralised, small, or marginal farmers. Leveraging existing financial structures and networks of development through the Scheme, he has developed an agrivoltaics system that sets a precedent for alternative pathways for agrivoltaics scale-out in a rural, decentralised Indian context. Since a lack of financial support to contribute to an initial investment installing agrivoltaics has been identified as a primary barrier to entry for farmers, the Hybrid Case provides a potential circumvention for farmers interested in the technology.

> If there is no subsidy…how will a common farmer even think of this? […] So, the farmer should rent whatever they can. What other option do they have? (AVS 1, 2023).

> Times are changing, so too are costs increasing [for solar…] We received a subsidy to cover the 5 lakh rupees. We [still] had to give around 1.25 lakhs (SP 2, 2023).

> Solar is not profitable that well. So, if people are switching to solar, they [developers] are losing revenue, and agrivoltaic solar would be like plants which are 2-megawatt sort of stuff. So of course, I mean, they'll lose that revenue. So that is the unwillingness. I mean, like that is the reason-- the loss that company will incur because of agrivoltaics or solar plant. So, yeah, how can I say, the deterrent for the discoms to promote agrivoltaics (AVS Developer, 2024).

The high upfront cost of solar pump installation is only justified because of the significant government subsidies available to farmers, however even with the financial support, farmers do still incur significant costs. This, in addition to the limited or non-existent promotion of agrivoltaics among crucial stakeholders like discoms, exemplifies the lower motivations to install agrivoltaics despite the potential benefits. As a potential alternative, the Hybrid Case represents an opportunity for more accessible, inclusive, and potentially equitable agrivoltaics if expectations for what agrivoltaics configurations can and might look like in decentralised and small-scale contexts remain flexible. In other words, by presenting an agrivoltaics system integrated into an existing solar pump development installed with the assistance of significant subsidies, the Hybrid Case illustrates a blueprint that other interested farmers might be able to adapt and implement for their own specific needs. Ultimately, this Case fosters further innovation by serving as a potential model for other farmers, contributing to the development of new adoption methods and enhancing social acceptability, both before and after the implementation of supportive financial policies.

There is further disruptive potential that has been observed in the field. At the Haryana KVK, the centre's focus was one predominately looking at water security in a region with deep groundwater levels and increasing salinisation. Thus, the centre has installed a rainwater harvesting system alongside their solar pump to educate local farmers in water-insecure Haryana (Image 9).

[Image 9: A solar array in cornfields for a solar pump, KVK Haryana (Author's Own, 2023).]

Rainwater harvesting has been noted as an efficient method of collecting freshwater runoff from solar panels, for use in irrigation or cleaning the panels themselves, and has been recognised as a good strategy for resource-use efficiency in agrivoltaics systems (Randle-Boggis et al., 2021). It has been integrated into the systems in Delhi, both at the KVK and the farmer-led system, but the system at the Haryana KVK is an early example of its integration with a solar pump. Unlike the established and more expensive add-on feature of rainwater harvesting integration on agrivoltaics systems (AVS Developer 2024), gutters were installed on KVK Haryana's buildings rather than the panels. However, the harvested rainwater is used to clean the panels more frequently and help replenish aquifers (KVK Haryana, 2023), which exemplifies another strategy for engendering dual-use resource efficiency in a solar pump configuration without requiring an expensive additional cost. Further, it establishes the possibility of such a feature's inclusion in future solar configurations.

In addition, the progressive agrivoltaics farmer in Maharashtra, has taken on the 'duty' of leading workshops at KVKs across the country for rural and small farmers on agrivoltaics (AVS 2, 2024). As a farmer whose driving factor for installing the technology was rooted in social responsibility, it is notable that this participant is using his existing knowledge developing agrivoltaics with neither financial assistance nor regulatory protection. By doing so, he demonstrates to other farmers that participation, and therefore just processes, in the energy transition through agrivoltaics is achievable despite these obstacles.

The abilities of the farmers in the Maharashtra and Hybrid Case to implement agrivoltaics or integrate agrivoltaics components respectively are indicative of their progressive nature and consequent capacity to take risks despite systemic and institutional barriers to agrivoltaics development. Further, the Maharashtra agrivoltaics farmer and the Haryana KVKs' focus on personal experimentation, training sessions, and providing capacity building opportunities for interested farmers engenders new pathways for farmer involvement in agrivoltaics. Such opportunities exemplify how agrivoltaics can be more accessible to the average farmer through adapting existing accepted, or incumbent, systems. While studies have found that farmers did not believe they could be involved in renewable energy development (Sareen & Kale, 2018; Stock & Sovacool, 2023), these cases exemplify how farmers can take back agency over their economic development, with which energy security is closely aligned in India (Lakhanpal, 2019). In doing so, Indian farmers have the potential to disrupt the current idea of solar implementation, especially how agrivoltaics are expected to be developed and what they are expected to look like, and instead produce new configurations that are more effective, accessible, and sustainable for a rural, decentralised context within which many Indian farmers reside. Thus, if restorative justice mitigates existing and preventing new distributional, recognitional, and procedural injustices, in this case dispossessive and exclusionary development practices (Hazrati & Heffron, 2021), utilising strategies such as centring farmer perspectives in decision-making may cause disruptive innovations to emerge that challenge the incumbent renewable energy regime that contributes to those existing injustices.

The disruptive potential of grassroots innovation and the empowerment of farmer perspectives and agency within the agrivoltaics transition also has the potential to reshape development networks (Joshi & Yenneti, 2020) and create *jugaad*, versatility, dynamism, and improvisation in innovation (Kumar, 2024; Prabhu & Jain, 2015). The formation, or in some cases the re-formation, of community networks of knowledge co-production also provides opportunities for increased knowledge accessibility. A participant from one NGO that works directly with rural and marginalised communities, including Dalit and Adivasi communities, recognised that it is the individual farmers who are 'actually making the decisions' about a technology on the ground because they know how to use it most 'effectively' (NGO 3, 2023). In other words, an academic or developer can inform an individual on how to use a technology in a specific way, however that individual may use it for another purpose that is more beneficial to them that outside stakeholders might not have considered (Kumar et al., 2021). Opportunities for knowledge co-production in instances such as these contribute to more inclusive energy systems and avenues for knowledge exchange between community members and stakeholders at multiple levels. Further, the integration of local knowledge can further 'enrich' a wider understanding of the technology itself (Melnyk & Singh, 2021: 50).

Nevertheless, through this disruptive process of experimentation and community network formation, Indian farmers are 're-configuring' the process of innovation by altering the methods of involvement, the formation of 'social, political, and learning networks', and the 'accumulation of knowledge' (Jacobssen & Bergek 2011: 45). Existing methods of installing agrivoltaics in India provide no 'reliable' financial assistance (AVS 2, 2024) or regulatory protection (AVS Developer, 2024) and has resulted in reluctant acceptance outcomes, such as in the case of the Delhi agrivoltaics farmers. In the absence of supportive systems or an agrivoltaics technology that translates to a smaller-scale context, they are exemplifying *jugaad* by adapting the technology to 'better fit' and work for their specific needs and lives (Kumar, 2024: 12). Unlike the established norm of agrivoltaics, Indian farmers live and work in a much smaller scale (NGO 3, 2023) and are thus producing new knowledge integrating agrivoltaics components on an equally new scale. Grassroots organisations recognise that farmers can 'convert hundreds of acres of land to sustainable farming systems, using different systems of doing so' and '[combining] productivity rather than [using] a single commodity' if they have the capacity and flexibility to do so (NGO 2, 2023). Despite existing implementation issues, farmers and grassroots organisations are leveraging existing methods of securing financial assistance, integrating dual-use strategies, and sharing new knowledge with other farmers through KVK networks and training opportunities. Rather than receiving information from national policy or decisionmakers, opportunities for rural farmers to learn from other experienced farmers re-establishes and reinforces the importance farmer-to-farmer networks of knowledge co-production and capacity building. While the central government lends a sense of legitimacy to existing policy, on-the-ground experience with implementation issues has eroded trust in top-down policies (AVS 2, 2024). Such erosion of trust, however, reinvigorates trust within farmer networks, fosters open communication between farmers, and improves acceptability of new innovations and opportunities for experimentation, in this case agrivoltaics.

> 'Farmers get a little bit more active and then they try to use this equipment for some other applications […] so, that further increases their interest in using this kind of technology' (NGO 3, 2023).

> It will take a while [to promote it]. But if one villager does it, you would want to be engaged in it too. Be a farmer. I also have knowledge [to give] (AVS 1, 2023).

Scholars recognise using existing systems of technological implementation in 'new and unexpected ways' contribute to acceptance (Liu et al., 2020: 315). In addition, it highlights the adaptability of farmers and the willingness to implement new innovations, which in turn indicates a pathway for agrivoltaics acceptance among rural farmers in India given that flexibility is allowed. Farmer-to-farmer exchange and knowledge co-production with KVKs and other community facing organisations generates an environment that enables the creation of innovative ideas and strategies in lieu of equitable, sustainable, and accessible policy implementation. Such local-level experimentation generates opportunities for equitable and sustainable solar energy implementation strategies that benefit rather than harm the farming communities in the way that commercial-scale solar has been observed by farmers and scholars alike to do (Singh, 2022; Dutta & Neilsen 2021). However, efforts support knowledge and policy co-development, through the recognition of farmers' ingenuity and adaptability, should be improved to encourage scale-out of inclusive agrivoltaics.

The Scheme has attempted to restore energy justice by providing opportunities to engage in the solar energy transition to decentralised farmers, however, as has been discussed in detail in previous chapters, it has faltered on multiple accounts and instead produces significant injustices requiring mitigation. The Scheme highlights existing institutional and network weaknesses wherein all effort for agrivoltaics research and development have been channelled into one version of implementation, such as prioritising large-scale agrivoltaics developments. Such efforts are recognised as weaknesses because they prevent a 'broader search' and process of knowledge development through a variety of perspectives (Jacobsson & Bergek, 2011: 48) and 'throttle' the creation of effective policy (National Researcher, 2023).

However, the growing prevalence of community-focused networks within farming communities represents a paradigm shift toward transformative restorative justice focused on capacity building and promotion of self-determination within and without institutional and systematic structures (Hazrati & Heffron, 2021; Schelly et al., 2020). A restorative approach is one that seeks remedies that are 'tailored to the harms that are specific to each community' (Wallsgrove et al., 2022: 149-150). Whereas the Scheme has miscommunicated the involvement process, misrepresented the quality of materials and support provided, and over-emphasised the role of agrivoltaics in the policy in a way that prioritises large-scale installations, the experimentation undertaken by smaller-scale and rural farmers represents a possibility of restoration. The innovative configurations and integration of agrivoltaics components by farmers, such as in the Hybrid Case, emphasise the 'duality' of restorative justice (Wallsgrove et al., 2022: 150). They emphasise a potential for a 'remaking or replacing what has been lost', such as inclusion within policy decision-making conversations, as well as 'seeking to repair wider social relationships and rectify injustice' (Wallsgrove et al., 2022: 150), such as exploitative land-grabbing for solar development (Singh, 2024). The emerging nature of agrivoltaics in India, and globally, means that achievement of long-term restorative justice can only be speculated here. However, the integration of agrivoltaics components illustrates an alternative pathway for agrivoltaics participation by existing solar pump farmers, or a method of circumventing an existing policy that lacks financial support for agrivoltaics to receive subsidies for solar pumps instead. Combined with the Maharashtra agrivoltaics farmer's enthusiasm for exchanging knowledge with local capacity building organisations so other farmers can learn how to integrate agrivoltaics, these cases highlight potential opportunities for medium, small, and marginal-scale farmer involvement in agrivoltaics while also offering an alternative to large-scale agrivoltaics development to which challenges the incumbent paradigm ascribes to. While there is significant potential for the application of restorative justice pre-development with the intention of preventing harm, there are countless instances where restorative justice must be addressed retroactively.

There are significant instances where communities historically adversely impacted by colonialisation continue to be dispossessed through the energy transition (Singh, 2024; Wallsgrove et al., 2021). Efforts at restorative justice for these communities have been observed as not recognising the historical but still-relevant damages to these communities, which impacts the effectiveness of any restorative action. Further, energy policy is argued as being 'ahistorical', or ignorant (whether deliberate or not) of the historical legacy that influences decision-making (Wallsgrove et al., 2021: 136; Mikeulwicz, 2019). While including history within energy policy decision-making improves restorative justice at the start of the process, it is also imperative that existing systems are evaluated and recognised as well to inform future, just systems. In the case of this thesis, no such restorative policy exists. However, the presence of innovative adaptations to agrivoltaics systems such as in the cases discussed here illustrate the potential for restorative justice if the perspectives of farmers themselves are considered. Currently, the farmers in this study are adapting through their own volition, however, should a policy be co-developed in recognition of the multiple potential configurations and implementation strategies of agrivoltaics led by farmers, both the adoption process and wider social acceptability might be improved.

Wallsgrove et al. (2021) recognise that restorative justice is most effectively applied pre-development, but that there are decades or even centuries of historical dispossession that influence policy development that hinders preventative restorative action, such as exclusion of certain demographics from decision-making processes and 'solar extractivist' land grabbing (Hu, 2023). Rather, a restorative justice perspective should be applied throughout and following an energy development process through the recognition of past and present harms, responsibility-taking, restitution, and rehabilitation.

It is impossible to delink India's current socio-political landscape, including its electrification renewable energy transition efforts, from its colonial history (Kale, 2014; Sareen & Kale, 2018). The influence of the neoliberal, market-forward central government is represented in new and emerging policies for solar development, as exemplified by the Scheme sanctioning substandard materials to cost-cut (AVS Developer, 2024) and overall inaccessibility despite its framing as a rural electrification and energy security policy. The 'throttling' of agrivoltaics in India due to systemically exclusionary policy such as the Scheme prevents easy accessibility of knowledge and effectively perpetuates a system that favours large commercial agrivoltaics developments. However, a technological innovation system that excludes crucial community perspectives excludes 'vibrant' experimentation and results in stagnating innovation (Jacobsson & Bergek 2011: 48). Thus, recognition of these barriers to widespread uptake of and further experimentation for equitable innovation and implementation of decentralised solar and agrivoltaics is the first step toward restorative justice.

Despite existing exclusionary conditions, India's rapid economic development renders it 'fertile ground' for testing potentially disruptive innovations, by taking 'foreign products designed for the developed world' that accommodate industry or commercial interests and adapting them to a specific local context (Liu et al., 2020: 317; Suseno, 2018). *Jugaadu* (improvisational) Indian farmers are already doing this (Kumar, 2024), as their disruptive potential from integrating agrivoltaics components within their pre-existing solar installations illustrates notions of 're-existence' wherein farmers leverage their own creativity to use existing institutions in their favour, often in cases absent of supportive policy (Walsh & Mignolo, 2018: 55). The Hybrid Case exemplifies this through the farmer's utilisation of existing policy, the Scheme in this case, through which he received multiple subsidies to install solar pumps and then integrate agrivoltaics components later. Through this re-existence, he illustrates opportunities for adapting existing solar into an agrivoltaics system where he benefits from energy, food, and water security. While his system does not meet the established conceptualisation of agrivoltaics, e.g. solar panels raised above crops, such as in the Delhi installation, the Hybrid Case exemplifies an alternative pathway for agrivoltaics adoption that other solar pump farmers could emulate.

Furthermore, this process is without the added pressure of over-reliance on outside, or even foreign, maintenance and support that often coincides with new innovations developed overseas in Global North settings (Sareen, 2021), such as traditionally configured agrivoltaics. While maintenance support is difficult to receive even in a state close to the capital, such as in Haryana, solar pumps are more commonplace than agrivoltaics and as such represent more community support should something need repairs (SP 2, 2023). Ultimately, participants recognise the innovative potential of farmers for informing a more equitable and sustainable implementation pathway:

> 'Farmers are very good at innovation. [While] they don't know how to quantify them [innovations], they are very good and [can] give us some insight into that. They would [be] very much, much better than the scientists are' (NGO 3, 2023).

Despite prevalent and undeniable uncertainties in experimentation at the grassroots level, it is widely recognised in innovation systems literature that integrating knowledge from groups that think in 'new and unexpected ways' from the incumbents, including scientists and decision-makers, is crucial not only for sustainable development, but also for social acceptance of a new technology (Liu et al., 2020: 50). Recognising that disruptive innovation is not an outcome, but a 'complete and progressive process' predicated on experimentation, including building upon existing and fostering cultures of knowledge co-production and mutual support in technological innovation, as well as fostering flexibility within conceptualisations of agrivoltaics, will enable the creation of a novel, more sustainable and equitable iteration of agrivoltaics more well-suited to the agricultural landscape in India (Si & Chen, 2020: 4). In other words, this 'creative destruction' of the existing paradigm of agrivoltaics implementation practices in India (Kimivaa & Kern 2015: 210), which mirror commercial-scale solar and favour large landowners, allows for many of India's farmers to participate in the renewable energy transition, improve their energy, water, and food security, and facilitate opportunities for improved self-determination.

> Once they [farmers] get the capability […] they start expanding it slowly. […] I see it as an incremental process rather than big companies coming in and you know, setting up the whole thing in one go (National Researcher, 2023).

Stakeholders believe that there is potential to upend the existing systems through bottom-up, grassroots implementation processes. While this National Researcher's perspective is only hypothetical, there is evidence of small-scale innovation through the ingenuity of farmers that represent a shift towards this kind of 'incremental process' towards widespread acceptance of agrivoltaics. Leveraging existing farmer knowledge, including those with agrivoltaics or dual-use experience, while also empowering their radical and dynamic 'frugal innovation' strategies to improve the capacities of other interested farmers and key implementation stakeholders alike fosters a culture of agrivoltaics development that facilitates participation in decision-making and potentially, a more holistic approach to agrivoltaics (Prabhu & Jain, 2015: 845; Naranayan, 2019). The Hybrid Case represents a potential future roadmap for this kind of incremental process that encourages knowledge exchange and co-production and thereby engendering restorative justice for many farmers in India interested in agrivoltaics, or the renewable energy transition, but who are otherwise prevented from participation due to efforts, either intentional or unintentional, to exclude them. While restorative practices are criticised in literature by the focus on private conduct and resolutions over broader public responsibilities (Wallsgrove et al., 2022; Hazrati & Heffron, 2021), the examination of select case studies of India's rural farmers illustrate that there is potential for communal restorative outcomes through agrivoltaics. An allowance for conceptual flexibility by the wider agrivoltaics scholarly community fosters a culture of experimentation on the ground that produces solutions tailored to a specific context and thus have higher rates of social acceptance due to a smoother integration process. The existence of knowledge co-production networks at the local level in India represents an ability for farmers to learn about agrivoltaics not as a technology unreachable without purchasing power, but as a technology that can be adapted to their specific needs.

Restorative justice can be examined as both an outcome and an ongoing process that requires recognition of past or present harms, taking responsibility, and mitigating those harms. When applied to discussions of emerging technologies including agrivoltaics and its innovations, it is difficult to evaluate the justice outcomes agrivoltaics installations will produce. As has been evaluated at length, the existing paradigm of solar development in India is exploitative for many rural communities, and it is likely that agrivoltaics development has the potential to mirror the harmful impacts of commercial-scale solar development if allowed to do so. However, recognition of both the potential harms based on previous experience with similar energy developments, as well as the potential opportunities for agrivoltaics within rural communities as exemplified by early adopters' experiences and perceptions, establishes a starting point for restoration. Responsibility-taking for injustices, both existing and potential, involves allowance for experimentation and opportunities for knowledge co-production and exchange. In other words, addressing the most noted condition of agrivoltaics acceptability—treating farmers as an equal stakeholder in the decision-making process—represents incumbents, such as researchers, developers, and other key decision-makers, taking responsibility for previous procedural and recognitional injustices. Consequently, the integration of community perspectives, experiences, and creativity contributes to mitigation, in this case the development of a more equitable agrivoltaics paradigm that is allowed to be flexible in definition and thus achievable by the average Indian farmer.

Experimentation requires evaluating restorative justice not only as an outcome but also an ongoing process because understanding how harms can be addressed, mitigated, and prevented from energy innovations such as agrivoltaics. Already, disruption to the paradigm of agrivoltaics implementation as evidenced by the Hybrid Case farmer's creativity, the Maharashtra agrivoltaics' farmer and the KVK's enthusiasm for capacity building, and the advocacy for marginalised communities to engage in the renewable energy transition by NGOs illustrate a re-making of existing systems to adapt the technology to decentralised environments, work on behalf of communities, and in so doing improve social perceptions and acceptability of the technology. Thus, this exemplifies the connection between opportunities for experimentation and disruptive innovation, restorative justice, and ultimately improved social acceptability through strengthened farmer networks.

7.5. Conclusion: Adaptable Agrivoltaics

The farmers interviewed for this thesis highlight unique experiences with decentralised solar and agrivoltaics, however their diverse perspectives underscore the importance of not only listening to their insights and observing their individual experiments but also considering how integrating them to further adapt agrivoltaics to a new context may mitigate previous energy injustices and foster opportunities for participation in the renewable energy transition.

While the participant in the Hybrid Case experiences a higher degree of freshwater security compared to other farmers interviewed for this study, he nevertheless integrates dual land-use strategies underneath and around his solar panels to boost water and land-use efficiency, even if at a small-scale. In addition, despite not having an agrivoltaics system specifically, the Haryana KVK's rainwater harvesting training workshops represent opportunities for water insecure farmers in the surrounding areas to learn about adaptations they may be able to make to their solar panels in the future. Further, the Maharashtra agrivoltaics farmer's enthusiasm for agrivoltaics has inspired him to lead workshops about agrivoltaics at various KVKs to encourage enthusiasm in other farmers as well. The combination of the inherent ingenuity of farmers as represented by the Hybrid Case with the utilisation and promotion of existing grassroots networks exemplified by the KVKs and progressive farmers motivated by a sense of common responsibility, produce a growing awareness of agrivoltaics and interest in participation. The promotion of such innovation through these networks fosters a culture of experimentation, increases willingness to accept the technology, and consequently produces an enabling environment for agrivoltaics.

The presence of disruptive and grassroots innovation and *jugaad* indicate a paradigmatic shift of agrivoltaics for community-level, small-scale use that has the potential to generate justice without which agrivoltaics will continue to perpetuate neocolonial and extractivist renewable energy implementation practices. Instead of preserving an iteration of agrivoltaics that benefits only large landowners at the expense of average farmers, empowering individual farmers or communities to improvise, experiment, and share their knowledge and context-specific experience may result in an agrivoltaics innovation that can be transferable across scales and regions, and eventually improving acceptance and equitable uptake scenarios. Ultimately, the development and proliferation of just agrivoltaics is dependent on a community's ability to adapt the technology to fit their everyday needs, without which agrivoltaics remain another technology imposed on them for 'progress' rather than sustainable development rooted in self-determination. While it is evident that this neoliberal, 'progress' mindset persists, as exemplified by the Scheme's applicability as an empty signifier, it is also apparent that rural, small-scale *jugaadu* farmers are improvising regardless of a lack of an enabling environment for agrivoltaics. Their innovations are disrupting the current trajectory of agrivoltaics implementation in India and may eventually inform a more just iteration of the technology that can be adapted to new contexts, thus improving its transferability.

The concepts of disruptive innovation and restorative justice have not yet been applied to solar energy or agrivoltaics, perhaps because solar energy generally falls within the market-forward mainstream of energy development despite its decentralised and disruptive potential. India's current paradigm of solar development prioritises large-scale developments that appease corporate interests and (neo)colonial 'wasteland' discourses (Singh, 2022; Baka, 2013). Rather than addressing concerns such as energy insecurity and infrastructural inaccessibility, India's incumbent solar energy regime remains focused on 'capital accumulation' that perpetuate exploitative, extractivist practices (Stock & Sovacool, 2023: 6). Referencing the single central government policy to address agrivoltaics, there is potential for the technology to also perpetuate this regime. However, there are opportunities to explore further innovative strategies to adapting agrivoltaics to new and emerging contexts, including but not limited to the Indian subcontinent. If provided the opportunities, farming communities globally have the capacity to introduce new methods of implementing and using agrivoltaics systems.

Agrivoltaics represent significant potential benefits across the food-energy-water nexus for farmers, but in policy discussions have been strict in definition and thus preventing opportunities for innovation. However, emerging scholarly discussions insist that agrivoltaics' regenerative potential should have an increased focus in research, emphasising that conceptualisations of the technology should be broadened to account for experimentation and innovation. There has also been limited research conducted on agrivoltaics innovations in emerging economies, including India, that consider on the ground realities and farmer perceptions based on lived experiences. As agrivoltaics scholarship grows, a combination of both considerations will need to be considered.

However, as a nascent technology, agrivoltaics can continue to evolve and adapt to new, decentralised contexts and challenge this paradigm if farmers are provided opportunities to experiment. Ultimately, if farmers are empowered as equal stakeholders in research and decision-making processes, then, as it has been argued, a more 'India-centric' approach to agrivoltaics can be developed.

Chapter 8: Conclusion: Adaptive Agrivoltaics and Avenues for Further Research

8.1. Introduction: A Review of the Objectives

The overarching objective of this thesis was to examine farmer and other crucial stakeholder perceptions of and lived experiences with agrivoltaics in India, a niche that has been little discussed in literature. To this end, an analytical framework utilising social acceptance, disruptive innovative, and energy justice perspectives was applied to contribute to developing a more robust understanding of the emerging and evolving perceptions, best practices, and future potential of agrivoltaics in South Asia, especially among small-scale and vulnerable farming communities. The aim of this research was to address a notable gap in the growing body of agrivoltaics scholarship, while centring farmer perspectives and as a result, illustrating the importance of knowledge co-production, flexibility in socio-technical configurations and regulatory definitions to encourage innovation, and experimentation to foster a just agrivoltaics transition.

The current body of global agrivoltaics research, while expanding rapidly, predominately focuses on case studies in the Global North. While there are more recent additions to the literature that take a comparative, global approach, there remains a notable gap considering farmer perceptions based on lived experiences in an emerging economy context. While there is emerging research based on pilot installations in India (Pulipaka et al., 2024), an examination of existing regulatory documentation and stakeholder testimonials indicate that agrivoltaics installations are directly transferring implementation practices from the Global North, which are not always applicable to the Indian context. In addition, the research undertaken in India is focused primarily on the technical aspects and have neither included farmer perceptions nor investigated how to encourage widespread farmer participation in the transition to agrivoltaics. Only feasibility studies and examinations of social perspectives pre-development have considered how to introduce agrivoltaics to farmers (Mahto et al., 2021; Trommsdorff et al., 2022; Agir et al., 2023). Nevertheless, there are opportunities for and devised by farmers that are changing the paradigm of agrivoltaics implementation and in the process, introducing possibilities for new pathways of agrivoltaics adoption in India.

I evaluated national, regional, academic, and local stakeholder perceptions in pursuit of this thesis' central objectives and develop a more robust understanding of emerging best practices for and feasibility of agrivoltaics scale-out in India. To this end, I conducted both desk and field-based research. Desk-based research involved a comprehensive document analysis to provide crucial contextual background and demonstrate the existing perceptions of agrivoltaics from elite and key decision-making stakeholders. The collection of primary data involved both virtual via Zoom and in-person semi-structured interviews with experts, central government officials, NGO employees, and farmers in New

Delhi, the Delhi Greenbelt, and Haryana. The interviews introduced important perspectives, by highlighting drivers of and barriers to technological adoption, conditions to be met to encourage acceptability, and innovative configurations driven by farmers.

The novelty of this research is two-fold. First, it analysed stakeholder, and notably farmer, perceptions of agrivoltaics based on practical and lived experiences with agrivoltaics and decentralised solar policy, development processes, and long-term implementation. This addresses a gap in the current agrivoltaics scholarship evaluating perceptions and social acceptance based on lived experiences globally, specifically in South Asia. Second, this research applied an analytical framework that not only investigated social acceptance based on lived experiences pre- and post-installation but also examined agrivoltaics through disruptive innovation and energy justice perspectives. In conducting this research, I hoped to contribute to rapidly growing body of agrivoltaics scholarship and analyse stakeholder perceptions and future avenues for equitable scale-out of agrivoltaics within an Indian context. While this study specifically examined agrivoltaics in northwestern India, the results and analysis presented here may be applied to other decentralised and emerging economy contexts.

8.2. Summary of Key Findings: The Challenges and Opportunities of Agrivoltaics Implementation

Over the course of this research, the challenges and opportunities associated with agrivoltaics implementation have been a central and overarching theme. National and regulatory documentation have first introduced the concept of agrivoltaics, however the technology's passing mention in a misrepresentative decentralised solar policy will likely have implications for social acceptability and adoption outcomes. Stakeholder perspectives of agrivoltaics emphasised both the vast opportunities associated with an equitable scale-out of the technology, however they caveat their enthusiasm with concerns over supportive regulation, financing schemes, quality and reliable infrastructure, and access to accurate information. Nevertheless, despite challenges for implementation, some farmers are taking the initiative to install or adapt agrivoltaics systems to fit their needs and in the process, presenting alternative pathways for participation and illustrating the importance of flexibility in agrivoltaics definitions and knowledge co-production opportunities.

The following sections will review and discuss the key findings of this project, before continuing with an examine the implications of these findings both for agrivoltaics implementation in India and further research.

8.2.1. Stakeholder Perceptions and Potential Enabling Environments

This first analysis chapter discussed and sought to answer the first research question: *How are agrivoltaics presented in policy and what are the implications for the development of an enabling environment for agrivoltaics in India?*

Agrivoltaics are introduced in national publications through a passing mention in a wider policy that promotes decentralised solar powered irrigation pumps for small-scale farmers. The Scheme allows for the development of solar energy on 'cultivable' lands provided that the solar panels are raised on stilts 'where crops can be grown below and […] sell RE [renewable energy] power to discoms' (Government of India, 2019a: 2). Otherwise, solar is only allowed on 'uncultivable' land (Government of India, 2019a). How these designations are defined remains ambiguous in the Scheme documentation, but the central government's Ministry of Statistics and Programme Implementation lists the nine land use classifications for land use indicates that cultivable land current not in use is 'waste land' despite opportunities for cultivation (Government of India, 2024). As scholars have emphasised, the designation of land as 'wasted' despite its potential often disregards the alternative uses for that land by disadvantaged communities and only appreciates its value when it is deemed productive (Baka, 2017; Singh, 2022). In many cases, this pursuit of productivity has included the renewable energy transition and has resulted in exploitation and dispossession of vulnerable communities in the interest of furthering national renewable energy goals (Hu, 2023). The designation of 'uncultivable' land is not included in this list, thus further indicating ambiguity on where solar can be installed and potentially facilitating further exploitation. Ultimately, agrivoltaics are presented in research reports as an opportunity for sustainable agriculture, farmer well-being, and energy and resource security (Pulipaka et al., 2024; Barron-Gafford et al., 2019). However, with no supportive policy that facilitates agrivoltaics installations for the average farmer in India, of whom many are classified as small-scale or marginal farmers, then agrivoltaics remains prohibitive to them.

Overall, the PM-KUSUM Scheme is misleading because while it is framed as a vehicle for farmer 'welfare' through subsidised decentralised solar, it is during the implementation process where the Scheme 'falters' (National Researcher, 2023). It is acknowledged by research participants that this policy has enabled the use of substandard materials for the installations, encouraged a shorter lifespan of the panels because of this poor quality of materials, and despite significant subsidisation, required high upfront costs to cover the remaining fees and potentially facilitate grid infrastructure updates (AVS Developer, 2024; National Researcher, 2023). It is also acknowledged that there is limited regulatory support for maintaining the systems over the 25-year government-mandated lifetime of the solar installations (KVK Delhi, 2023). Thus, when the substandard materials are integrated and they are damaged, there are few opportunities for rural farmers to receive support, which ultimately damages perceptions of the technology. While there are concerns regarding allowing farmers to experiment with agrivoltaics configurations and in the process damaging the reputation of the technology (Moore, 2021), the implementation of solar energy with substandard materials and the prohibitive measures that prevent adoption of agrivoltaics in general also have the potential to detrimentally impact social perceptions of the technology.

Most notably, the requirements to receive subsidisation for solar pumps remain outside the capabilities of the average farmer (NGO 1, 2023). Further, the introduction of agrivoltaics in this Scheme does not fall under subsidisation in hopes that the market will ‘do the rest’, thus rendering the technology even more inaccessible to farmers who cannot afford the high upfront cost (National Researcher, 2023). However, the market-oriented approach in this Scheme does not consider the implications of requiring ‘proximity to the grid’ to receive economic benefits from feed-in tariffs (Government of India, 2019a: 2). For many decentralised farmers with unreliable or no access to electricity infrastructure, there is acknowledgment that they would not be able to participate in this transition and may even foster unfavourable opinions of this Scheme due to this oversight (NGO 2, 2023). Each of these factors represent a significant barrier to entry for farmers and individually, they are recognised by national stakeholders (GOI Employee, 2023). While solar pump installations proliferate in India due to their existence as an established technology, the combined barriers to widespread agrivoltaics adoption effectively prohibit any farmer without the financial or experiential capacity from participation.

Essentially, while this Scheme is promoted as a potential vehicle for smaller-scale and rural farmer electrification and improved well-being, through its ambiguous land requirements, financing structures, and poor implementation mechanisms, it instead facilitates a market-oriented process that prioritises large-scale solar installations. The policy itself acts as an empty signifier because it represents a concept, or a promise, of livelihood and resource security for farmers through solar development and ownership. However, it instead produces only a limited enabling environment for decentralised solar irrigation pumps and does not produce such an enabling environment at all for agrivoltaics for the average farmer.

8.2.2. Evaluating Conditional Acceptance of Agrivoltaics

The second analysis chapter addresses the research question: *What are the drivers, barriers, and opportunities associated with agrivoltaics development?* By elaborating on the barriers many farmers experience when implementing decentralised solar pumps and agrivoltaics systems. However, by centring the farmer perspectives in this chapter, a more robust understanding of the implications of a misleading policy and overarching national perception of the solar transition in India is developed.

The documentation analysed in the previous chapter present agrivoltaics as a vehicle for farmer welfare and an opportunity for resource security, however there are no current financial systems in place that guarantee reliable and 'reasonable' support that provide a sense of security for many farmers (AVS 2, 2024). Thus, while farmers may be interested in the technology, there is lower social acceptability and subsequent adoption because it appears to be unfeasible. Furthermore, there are concerns over exploitation and dispossession for renewable energy developments that influence distrust in central government interventions (Singh, 2022; Alexandre et al., 2018). Even in the technology's nascency, one interview participant already has acknowledged that agrivoltaics installations are viewed as a temporary measure by larger landowning farmers to earn additional income while waiting for land prices to increase to sell (AVS Developer, 2024). It is evident that the limited supportive policy for agrivoltaics, including regulatory protections for installation processes and financial support, is already facilitating implementation processes that favour larger configurations over rendering the technology more accessible to the average user. Ultimately, the current policy landscape does not provide an enabling environment for agrivoltaics.

Nonetheless, Indian farmers interviewed for this thesis are aware of and interested in agrivoltaics and may be interested in it due to the improved energy and financial security, given certain conditions are met. These conditions include grid connectivity, reliable infrastructure, regulatory protections, and a reduction in the 25-year lease period that to many farmers feels too long to dedicate their land to solar.

While the conditions emphasised by both solar pump and agrivoltaics Indian farmers in the Delhi Greenbelt, Haryana, and Maharashtra reflect criteria for acceptability acknowledged by national and elite stakeholders, the farmers' perspectives underscore the importance of considering on the ground realities and community perspectives. The farmers' insights and perspectives are grounded in lived experiences. They represent the inherent ingenuity in farmers, as they have had to learn by doing either alone or through existing farmer networks, and their conditions for accepting agrivoltaics are rooted on those lived experiences, including the challenges they experience every day as small-scale farmers. Thus, their experience adapting to climate variability, the increasing insecurity of the agricultural sector, and simultaneously integrating solar energy lends additional significance and legitimacy to other stakeholder perspectives. Whereas national policy that references agrivoltaics has lower levels of legitimacy because of the acknowledged miscommunication and implementation challenges affiliated with it, implementation practices grounded in farmer realities and based on knowledge co-production and exchange may contribute a greater sense of agency, as well as a more inclusive and sustainable scale-out of agrivoltaics (Glover et al, 2019). In other words, empowering farmers and their experiences as equal stakeholders in the research, development, and implementation processes may engender a more acceptable technology.

8.2.3. Challenging the Paradigm of Agrivoltaics Implementation

The final discussion chapter emphasises the significance of experimentation and flexibility in agrivoltaics implementation processes. The objective of this chapter was to address the final research question: *In what ways do Indian farmers influence, inform, and disrupt the perceptions, innovation, and implementation of agrivoltaics?*

Through the analysis of the hybrid case study wherein one solar pump farmer has integrated agrivoltaics components into his configuration, this chapter argued that agrivoltaics have disruptive potential within the solar transition. It also argued that facilitating experimentation with new and 'unexpected' configurations led by farmers have the potential to disrupt the existing paradigm of agrivoltaics conceptualisations and offer an example of alternative pathways to development in decentralised and smaller-scale contexts (Liu et al, 2023: 55).

It was made evident that farmers have the capacity to engage in new ownership configurations of agrivoltaics (AVS 1, 2023), adapt existing decentralised solar installations to integrate dual-use components and experience additional benefits (Hybrid Case, 2023), and contribute to processes of knowledge co-production, capacity building, and skills development (AVS 2, 2024). Concerns over damaging the reputation of agrivoltaics have been raised to justify preventative measures for experimentation and creating 'pseudo-agrivoltaics' (Torma & Aschermann-Witzel, 2023: 617). While this claim was made by one stakeholder in another European study, similar sentiments have been expressed by participants in this research regarding fears of exploitation of land and water resources under the pretence of sustainable energy production (NGO 2, 2023). However, this bias also disallows farmers from adapting the agrivoltaics systems or integrating certain components to meet their unique environmental and socio-economic contexts and needs. Such inhibition of experimentation also may result in stagnating innovation and the consequent proliferation of incumbent implementation strategies that prioritise large-scale, high-cost developments (Goyal & Howlett, 2018; Kivimaa & Kern, 2016).

Nevertheless, opportunities for knowledge co-production that allow for farmer experimentation and knowledge exchange between stakeholder levels and within farmer networks have the potential to produce an agrivoltaics standard that is more inclusive to the average farmer in India. Knowledge co-production would require a more incremental process—including widespread and intensive stakeholder workshops, opportunities to engage collaboratively in the design of regulations and skills development—that previously was considered a challenged undertaking beyond the capabilities of government officials (GOI Employee, 2023). However, if such an incremental process of engendering farmer capacity building and participation is organised and facilitated, then there is potential for disruption to the existing paradigm of agrivoltaics implementation strategies in India as well as the incumbent conceptualisations of the technology overall.

Although improved access to accurate information and inclusion in decision-making processes would significantly benefit farmers and inform more equitable agrivoltaics policy, the current reality necessitates that many farmers rely on their own ingenuity and networks. In lieu of these supportive processes, farmers must adapt existing solar developments or implement agrivoltaics components using innovative methods to participate in and benefit from the co-benefits of a dual-use energy system.

8.3. Indian Agrivoltaics and the Implications of this Research

This research has aimed to address a gap in the literature investigating agrivoltaics in India, specifically farmer perceptions based on lived experiences with both agrivoltaics and decentralised solar, in this case solar irrigation pumps. The current body of agrivoltaics research, despite its current exponential expansion, predominantly focuses on case studies in the Global North. These include technical studies, feasibility studies, and qualitative research evaluating stakeholder perceptions of the technology, usually pre-adoption (Schindele et al, 2020; Pascaris et al, 2021; Trommsdorff et al., 2022; Moore et al., 2022; Torma & Aschermann-Witzel, 2024). However, while there is a growing body of research evaluating social acceptance and perceptions of agrivoltaics in emerging economies (Agir et al., 2023; Bilich et al, 2024), examinations of farmer perceptions based on lived experiences are limited.

Likewise, current agrivoltaics policies introduced globally have contributed to an established definition of agrivoltaics for the explicit purpose of ensuring that neither agricultural production nor energy generation is detrimentally affected by the other (Worringham, 2021). However, the established conceptualisation, which involves solar panels raised above agricultural land to allow for machinery and predicated on improving overall productivity of the land compared to only agriculture or energy generation (Agostini et al, 2021), contributes to regulatory 'lock-in' (Kivimaa & Kern, 2016: 210). This lock-in results in innovative stagnation that preserves agrivoltaics as only a commercial or large-scale solar technology and in the process, disincentivises smaller farmers from attempting to adopt and adapt it.

India has no regulatory protections for agriculture under agrivoltaics installations to the same degree as its European, North American, and Japanese counterparts (Tajima et al, 2021). This may be reflective of the current Hindu-nationalist political system that prioritises market-driven approaches to development. Historical solar installations have trended toward large-scale developments, which are often dispossessive in nature (Singh, 2022). Farmers have expressed concerns over renewable energy interventions due to awareness of their counterparts moved off 'unproductive' land to foster a more 'productive' use of the land and uplifting the national profile in a process known as 'solar extractivism' (Hu, 2023: 2; Yenneti & Day, 2016). The 'neoliberal' land grabbing that has accompanied large-scale solar developments in India have ultimately contributed to complicated perceptions of the technology, and exemplify the spectrum of reluctant acceptance (Levien, 2018: 175).

This examination of the conditions that would engender social acceptance has involved the application of reluctant acceptance perspectives to represent the diverse perceptions of Indian farmers pre- and post-adoption. Originating from nuclear energy studies, a reluctant social acceptance lens has not yet been applied to agrivoltaics previously. However, the concept acknowledges the range of emotional responses to an energy installation, from enthusiasm and apathy to disgust, throughout the development process, from introduction to long-term effects (Haikola et al, 2017; Guo & Ren, 2017). Farmers who are interested in agrivoltaics contend with a colonial history that facilitated generations of exploitation through 'civilising-enlightening' development efforts, ongoing dispossession through market-driven, productivity-focused renewable energy implementation, and limited protections, support, or access to accurate information (Singh, 2022: 407: Stock & Sovacool, 2022). Thus, it follows that farmers would experience a complicated spectrum of perceptions for an innovation like agrivoltaics. Without regulatory and financial support, improved trust between the central government and local farmers, and opportunities for farmer involvement in the development process, agrivoltaics will not be scaled out in any 'meaningful' way.

'Meaningful' in this context refers to the effective, equitable, and sustainable integration of agrivoltaics into an Indian context, specifically considering the diverse perspectives and requirements of farmers for their solar installation (Glover et al, 2019: 171). Essentially, agrivoltaics are theorised to achieve holistic benefits across the food-energy-water nexus through improved resource security and due to the inherently scalable nature of solar energy in general, it is expected that agrivoltaics would likewise be transferable to multiple contexts. However, this transferability is predicated on the ability for local farmer and stakeholder participation in the decision-making and development processes to facilitate a more localised, meaningful version of agrivoltaics. National and community-facing stakeholders alike have emphasised the importance of taking an 'India-centric' approach, however they likewise acknowledge that the key decision-makers continue to emulate the European and North American, or large-scale and thus more economically viable, configurations, despite policy like the Scheme proposing the opposite as possible (National Researcher, 2023; GOI Employee, 2023; AVS Developer, 2024). As exemplified by the discussion of the Scheme, there is indeed a disconnect between creating an enabling environment for the technology independent of who has the capacity to implement it and an enabling environment for the just and equitable introduction of that technology rooted in the knowledge, perspectives, and experiences of the communities who might benefit the most from its co-benefits. Ultimately, understanding farmer perceptions of agrivoltaics, both historic experiences with energy development and current practical knowledge with decentralised solar, and innovative capacities contribute to achieving the latter enabling environment.

While the Scheme is undoubtedly an excellent first step towards developing a sustainable agrivoltaics policy that promotes a more realistic 'India-centric' approach—one that supports rather than excludes small farmer participation in the agrivoltaics transition—it is evident that updated iterations of the Scheme and any new agrivoltaics-specific policy must consider farmer perceptions. Farmers represent an influential demographic in India despite many of them being classified as small or marginal. As the participants in this study have illustrated, Indian farmers possess crucial experiential knowledge and innovative capacity that if considered in policy development and research, contribute to a more holistic, accessible, and just agrivoltaics better suited for an Indian context.

Similarly, there must be consideration for flexibility in definitions and allowance for farmer experimentation to improve transferability of agrivoltaics. Concerns over 'minimising the impact' of agrivoltaics or damaging its reputation due to this experimentation only perpetuate bias on who can participate in the renewable energy transition (Torma & Aschermann-Witzel, 2023: 617). Rather, experimentation will likely contribute to a more robust knowledge base, rooted in experiential knowledge, co-development, and adaptive potential for new environments and contexts (Glover et al, 2019). Acknowledging how their unique expertise may improve agrivoltaics' effectiveness, both as a symbiotic agricultural, water security, and energy generation system adapted to a specific environment as well as capable of meeting a farmer's everyday needs. Agrivoltaics remain an emerging innovation and much of its early research relies on Western examples and experiences that may not be applicable to alternate contexts with conflicting, government processes, diverse community structures, and distrust for energy system developments based on historic exploitation. While the body of agrivoltaics research is swiftly expanding to include case studies and perspectives in the Global South, agrivoltaics is still being implemented in India based on neoliberal, large-scale iterations rather than with the holistic, India-centric potential in mind. Large-scale agrivoltaics have a role in the energy transition, yet an increased focus on co-development strategies has the potential to create an agrivoltaics that is more applicable to new contexts, thus improving its regional transferability.

Despite the barriers that farmers face, these challenges also represent opportunities for experimentation, as exemplified by the Hybrid Case. While innovation and experimentation are possible under enabling environments and supportive regulatory structures, it is evident that regulatory tunnel vision in India has prevented 'outsider' participation and consequently, farmers are establishing novel approaches to agrivoltaics development and configurations (Jacobssen & Bergek, 2011: 48). Nevertheless, as evidenced by the innovative farmers interviewed during this thesis' field work, Indian farmers, whether decentralised or grid-connected, can contribute to the development of new standards of agrivoltaics implementation. Whether using collaborative farming, integrating dual-use practices in an off-grid solar irrigation pump system, or empowering other farmers through leading capacity building workshops, it is evident that Indian farmers are more than capable of leading a grassroots approach to the establishment of inclusive agrivoltaics. While this study's findings specifically refer to a northwestern India context, the insights discussed do possess a degree of transferability in other Global South and emerging economy contexts while underscoring the importance of further research in new contexts. Agrivoltaics is theorised to be a regenerative, climate-mitigating approach to the renewable energy transition, however without further research into its implications for other contexts, such as in emerging economies, off-grid and decentralised regions, and for disadvantaged communities, agrivoltaics will continue to remain beyond the capabilities of a significant proportion of the world's agricultural communities.

8.4. Limitations and Reflexivity

Despite the risk management strategies and ethical preparation for field work, it was nevertheless imperative to remain reflexive of my own positionality during the data collection and analysis process. As a researcher engaging with participants directly and utilising participatory methods, it is important to acknowledge that research is never objective. Like agrivoltaics, research is highly contextual, and any results will be influenced by my own positionality, including my own assumptions, motivations to complete the research, and research objectives. Therefore, it is important to critically reflect on the research process, from data collection to analysis, to develop a more credible and robust product, but also a deeper understanding of the work itself (Dodgeson 2019; Reid et al 2018).

Ultimately, I am a female, foreign, English-speaking researcher who was reliant upon the assistance and support of my host institution, ICAR-IARI, to facilitate meetings with other government officials and community members. Learning a few phrases in Hindi is helpful for introductions, however I was unable to conduct interviews in the language without assistance from an interpreter, in this case another PhD student who took time from her schedule to offer support in the field. Translation is a complex issue because cultural nuance can be lost or minimised and will thus impact how I evaluate the data. While I have attempted to 'foreignise' the data to maintain some of that nuance even after translation, the text and my subsequent analysis nonetheless was influenced by how I was able to interpret it.

Furthermore, there have been several instances throughout the field visit where methodologies had to be altered in the moment, such as acquiring verbal consent from farmers, which required me to critically analyse my decisions in those moments. I made the decision to pursue verbal consent because some of the participants' English capability was understood to not be strong enough to fully understand the information sheet and consent form without explanation. In addition, I was mindful of taking time away from their work and aware of my own status as a foreign researcher coming across as demanding and expecting interactions rather than as one receiving their help. While it was not my intention, and it may not have been perceived as such, I was aware of my inability to converse in Hindi, which further established me as 'separate' and perhaps even neocolonial in presence due to unintentional but nevertheless present asymmetrical power dynamics between the researcher and the participant (Dodgeson, 2019). After all, the purpose of my field work is to achieve my PhD, and while my research contribution intentions are decidedly not selfish, my presence is not entirely altruistic. This perception may have impacted the nature of responses I received and thus will influence the text that is available for me to interpret.

Ultimately, the researcher themself is a research tool that impacts data collection and must be understood as such throughout the duration of the project, specifically in the analysis phase. How the data was collected and produced, and how it was interpreted is the responsibility of the researcher and thus dependent on my own understanding and perceptions. Nevertheless, turning the lens back on myself and acknowledging my presence and influence over the process had the intention to produce a more vigorous examination of the implications and perceptions of agrivoltaics in an Indian context.

8.5. Opportunities for Future Research

This novel research aimed to address notable gaps in agrivoltaics scholarship, specifically pertaining to the evaluation of farmer perceptions based on lived experiences through a (reluctant) social acceptance, disruptive innovation, and energy justice framework. However, there remain significant opportunities for further research that can build on this thesis and address its limitations.

For instance, there are opportunities to pursue further research investigating the feasibility of and lived experiences with agrivoltaics in other emerging economies, unique environments and geographical locations, and among previously unconsidered communities, such as indigenous and other marginalised populations. Specifically regarding agrivoltaics research in India, there are also other avenues for further research. First, it was recognised by various participants in this study that women play a significant role in agriculture, such as contributing to most day-to-day cultivation, but represent a minority of landowners in India (National Researcher, 2023; NGO 3, 2024). Women are understood as significant decision-makers and potential community leaders in renewable energy transitions, however both their absence in India-centric research is significant (Beuchler, et al., 2020; Sovacool, et al., 2013). While the importance of considering farmers an equal stakeholder has been well-documented, the role of women at the local level has not been explored at length in existing research despite further potential for disruptions to the incumbent norm and decision-making process they might provide. Solar development is male dominated at the industry and policymaking level, but 'in all villages, wherever the activities are happening in a smaller scale, that is driven by women' (NGO 3, 2023). Women farmers represent a significant proportion of agricultural workers in India but are often disregarded in conversations of solar energy integration within the industry (National Researcher, 2023). While their perspective has not been included in this project due to time limitations, and represents an opportunity for further research, their role and influence should also be considered when discussing both potential impacts of agrivoltaics systems at the local level as well as innovations their perspective can, and already likely is, informing.

Thus, further research specifically investigating the role of women, and potentially Hijra (nationally recognised third gender) individuals, in agriculture and energy transitions in India would provide crucial insights to ensure equitable provision of energy and an inclusive implementation of agrivoltaics. Finally, further research analysing agrivoltaics best practices conducted in one or more of India's mother tongues (other than English) may not only attract more participants that would otherwise not be able to contribute but also render the results more accessible to those who use those languages. My research hopefully represents the first of many studies that investigate agrivoltaics best practices and disseminate its results among communities most likely to benefit from the technology.

In addition, there is scope for future research examining new configurations and scales of agrivoltaics in India, including urban areas and previously unexplored climates such as the tropical southern and eastern states or mountainous northern ones. Whether investigating new contexts or communities in agrivoltaics implementation, it will also be imperative that more research is dedicated to longitudinal studies to begin to understand the long-term implications of agrivoltaics installations on the land and agricultural production, farmer perceptions, and determine end-of-lifetime standards for the materials. Since practical agrivoltaics research remains in its early stages, there have been no opportunities for this nature of research however it will become more important as agrivoltaics grow in popularity. End-of-life practices from historic solar installations or the existing dual-use systems employed in Japan (Tajima & Iida, 2020) may provide insights into best practices, however as with all the new technologies, the sheer scale of disposal and potential recycling needs will need to be addressed. Further, previous solar energy best practices research cannot be transferred to examinations of long-term implications of agrivoltaics, thus there is a crucial need for this nature of research.

The expansion of agrivoltaics research into these, and other contexts not mentioned here, will contribute to the development of a more comprehensive body of literature than can influence best practices for agrivoltaics implementation and policy development. It was the aim of this thesis to contribute one facet to this emerging discipline, but it is evident that agrivoltaics is fertile ground for rich research and its potential has not yet been fully explored.

8.6. Conclusion

Agrivoltaics represent an innovative technology with significant potential for mitigating concerns over climate variability, insecure energy, food, and water resources, and land competition prevalent in renewable energy arguments. However, due to the relative nascency of the innovation, there is limited policy and regulatory protections for agrivoltaics. Policy that does exist focuses on the development of a specific definition of the technology and is predicated on the assurance that neither agricultural production nor energy generation would be significantly impacted by the other (Worringham, 2021). However, while the proliferation of agrivoltaics policy and guidelines is important for technological diffusion, there are concerns that such specific definitions and standard may contribute to lock-in and thus innovative stagnation (Kivimaa & Kern, 2016).

Ultimately, agrivoltaics cannot be constrained to a single definition or configuration. Opportunities for flexible definitions that allow for farmer and other stakeholder experimentation to adapt agrivoltaics to their specific, localised needs will be crucial for the inclusive and just scale-out of agrivoltaics. Despite limited regulation or protections in India, in addition to a lack of an enabling environment for agrivoltaics, Indian farmers are steadily showing interest in agrivoltaics and unique configurations adapted to their specific needs, whether through improved energy or freshwater security, or leveraging their experience to facilitate further skills development and knowledge exchange within and without farmer networks.

As various stakeholders have indicated, if agrivoltaics are to perpetuate the incumbent processes of renewable energy implementation, it is 'better' to not attempt to introduce the technology at all (GOI Employee, 2023). However, if opportunities for capacity building, knowledge co-production between researchers, elites, key decision-makers, and farmers are generated and sustained, financial and legal protections are strengthened, then a more equitable policy approach may result. In the northwest, Indian farmers are already indicating that more inclusive agrivoltaics are possible through their willingness to experiment, disseminate knowledge through their networks, and leverage existing financial support systems in their favour where none exist for agrivoltaics. Indian farmers can disrupt the paradigm of agrivoltaics implementation and informing a roadmap for more flexible conceptualisations and thus policy of the technology, exemplified by the innovative configurations and knowledge-exchange opportunities they have contributed to. The only remaining course of action is to continue to contribute to the growing body of research documenting and investigating their efforts and empowering their diverse experiences and perspectives in the process to determine whether such inclusive and equitable agrivoltaics come to fruition. From what I observed in the field and learned from farmers, I am optimistic about their capabilities and their innovative potential, however their empowerment will depend on recognition of their potential at the regional and national levels to facilitate a shift in regulatory focus to one that prioritises their perspectives.

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Appendix A: Interview Questions

National Stakeholders:

- Can you talk me through the decision-making process that resulted in the KVK programme and funding for agrivoltaics pilot projects?
- Can you talk me through the decision-making process that resulted in the PM KUSUM scheme?
    - How involved were regional and local stakeholders?
    - What level of involvement or participation by farmers was there in the decision-making process?
    - Were there other stakeholders or groups involved, whose opinions were key to the decision-making process?
    - Were there other stakeholders or groups that you think should have been involved or represented?
- What have been the key success factors so far?
- What have been the biggest challenges faced so far?
- If you could change or add anything to the scheme that you think would make the scheme more successful, what would it be?
- To you, what do you think the most important aspect of agrivoltaics is presently? Why?
- To you, what do you think the most important aspect of agrivoltaics will be in the future? Why?
- What do you think the most important aspect of agrivoltaics is for the country? Why?
- What do you think the most important aspect of agrivoltaics is for the farming community? Why?

Experts and Developers:

- To you, what do you think the most important aspect of agrivoltaics is presently? Why?
- To you, what do you think the most important aspect of agrivoltaics will be in the future? Why?
- What do you think the most important aspect of agrivoltaics is for the country? Why?
- What do you think the most important aspect of agrivoltaics is for the farming community? Why?
- Do you think, in your opinion, agrivoltaics are currently a just [renewable] energy source? Why or why not?

- What advancements or considerations would agrivoltaics technology and policy need to make in order for the technology to be just?
- What is the possibility of these considerations being made?
- What is preventing these considerations being made?
- Why do you think agrivoltaics is a feasible energy source? And in India specifically?
- What is the biggest challenge, in your opinion, to future implementation of agrivoltaics?
- How does this compare to a local stakeholder, or farmer's, opinion on the biggest challenges?
- What do you think the future of agrivoltaics looks like in India?
    - For example, implications for women, rural communities, etc.

Community Participants (e.g. farmers):

- Walk me through the process of installing the system?
    - Follow-up prompts can include:
        - How did you first learn about agrivoltaics?
            - From the news/media, word of mouth, or approached by NGO/academic/developer/local or regional government?
        - What aspects drew you to the idea of agrivoltaics in the first place? What aspects of agrivoltaics inspired you to engage with the technology in the first place?
        - Were you aware of the KVK programme beforehand?
        - Did you approach developers yourself or did they approach you?
        - How involved were you and others in your community in the development/installation process?
            - What do I mean by this process? It can mean anything about the process of implementing the system, from reaching out to developers, regional government about subsidies (KVK), or NGOs (e.g. CIPT), deciding the best placement of the system, the management of the system, where the electricity and crops produced will go, the long-term plan such as what will happen once the system reaches end of life, etc.
        - What level of participation did you hope to have? If you did the process again, would you be more or less active in the development process?
- Can you talk me through how the agrivoltaics system works throughout the year, including multiple seasons, such as drought and monsoon?
    - This will give insight to transferability of the technology, resilience of the system, and lived experience

- Tell me about your average day engaging with the agrivoltaics system?
    - What do you do on an average day?
- How do you think about the system now, compared to how you thought about it at the beginning?

Photovoice questions/prompts: (a photograph will be taken by me, directed by the participant, to correspond with each response)

- What do you consider to be the most important part of the agrivoltaics system to you?
    - Follow up: why do you think this way personally?
- What do you consider to be the most important part of the agrivoltaics system to your community?
- What do you consider to be the most important part of the agrivoltaics system in general? E.g. electricity, food, water security?
    - This can be the same as the most important part to you, but this question aims to get the main draw of agrivoltaics
- What aspect of the system would you change, if you could? Why?

Appendix B: Interview Questions Updated for Ease of Translation

For developers/staff/experts:

1. What do you think is the most important aspect of agrivoltaics? Why?
2. Specifically, what role do you think agrivoltaics plays in achieving India's renewable energy goals?
3. What do you think is the most important aspect of agrivoltaics for farmers? Why?
4. What changes need to be made for agrivoltaics to be scaled up in the future?
5. What is the biggest challenge facing future agrivoltaics implementation?
6. Why do you think there is no standard policy or regulation for agrivoltaics yet?
7. What are the key successes and challenges you have faced with implementing agrivoltaics here?
8. How do the different seasons impact the system's overall efficiency?
9. What changes would you like to see to make the programme more successful?
10. What were the motivations behind the development of this programme?
11. What would you change about the current configuration if you could?

For farmers→

1. What is the size of the farm and what is the capacity of the solar panels?
2. What crops do you grow?
3. How do you irrigate?
4. How did you learn about this programme and agrivoltaics?
5. What motivated you to get involved?
6. How involved were you in the system development process? Did you advise on the configuration or design?
7. How much support did you receive when making these decisions?
8. What did you think about agrivoltaics in the beginning?
9. How does the agrivoltaics system work in different seasons? For example, how effective are the panels at reducing crop heat stress and do the crops keep the panels cool?
10. How do the panels affect day to day farm work?
11. How much trial and error did you have to do when deciding which crops to plant underneath the solar panels?
12. How is the current drought impacting how you work with the system?
13. Are you happy with the current configuration?

14. What would you change if you could?
15. Do you feel like the 25-year lease period is too long or too short?

Modified photovoice: please direct me to take photos according to these prompts. You can interpret the questions however you want.

1. What is the most important aspect of the system to you?
2. What is the most important aspect of the system in general?
3. What part are you most happy with?
4. What aspect would you change if you could?