AgriVoltaics World Conference 2023
Legal Framework & Public Policies
https://doi.org/10.52825/agripv.v2i.990

Published: 23 May 2024

The Socio-Technical Dynamics of Agrivoltaics in Japan

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Abstract. Japan is a pioneer in agrivoltaics with over twenty years of practical experience and already 3,474 permitted projects by 2020. Agrivoltaics can potentially help to solve pressing societal challenges, such as decarbonization, rural revitalization, food and energy security, and disaster resiliency in a country with very limited suitable land. Nevertheless, agrivoltaics remains a niche technology even twenty years after its first implementation. This study analyzes the socio-technical dynamics to identify the barriers and opportunities for agrivoltaics in Japan. The analysis of governmental documents, statistical data, and academic publications in combination with expert interviews with farmers, a business operator, and governmental officials show that the lack of a clear vision for agrivoltaics by the government, persistent legal barriers, insufficient research, declining economic incentives, and cultural resistance hinder a faster diffusion of agrivoltaics in Japan.

Keywords: Agrivoltaics, Japan, Socio-Technical Dynamics, Policy Barriers

1. Introduction

The idea of “solar sharing”, synonymous with agrivoltaics, was introduced in Japan twenty years ago by the pioneer Akira Nagashima. One year later in 2004, the first pilot project was established in Chiba and a patent was released the following year [1]. This early adoption makes Japan a pioneer with the longest practical implementation of agrivoltaics globally. For a long time, however, the advancement of agrivoltaics was happening unknowingly to stakeholders outside of Japan. English articles and presentations in international contexts only recently emerged. This research paper will contribute to sharing the knowledge and lessons learned from two decades of agrivoltaics in Japan by analyzing its socio-technical dynamics.

The socio-technical approach by Geels et al. [2] emphasizes the need to consider the mutually dependent technological, economic, and social processes of low-carbon transitions. The emergence of niche innovation, such as agrivoltaics, is shaped by social and cultural factors and happens in the context of socio-technical regimes and the socio-technical landscape. These niche technologies are typically first developed by small actors and are initially embraced by early adopters. The established socio-technical regimes are often hesitant to facilitate these new technologies that may disrupt the status quo. The socio-technical landscape, i.e., the broader societal context, is influential in shaping the opportunities and barriers to the advancement of technologies. Relevant factors include public opinion, market conditions, and global trends. It is necessary to understand the processes within and between the niche innovation, socio-technical regimes, and the socio-technical landscape to be able to successfully facilitate the transition [2]. Moreover, the emergence of niche technologies happens in the context of other societal goals that are given higher priorities. Overall, it is crucial to align the interests of relevant stakeholders, such as the government, industry, and society, in order to establish reinforcing ‘ambition loops’ that enable a sustainable transition [3]. Especially in the early emergence stage, niche technologies need support since they generally still have low performance and high costs and often face opposition and political pressure from incumbents. Therefore, the establishment of niche technologies in existing systems can be challenging without assistance. Decision-makers can introduce a variety of policy instruments to increase the opportunities for niche technologies if the new technology is considered to be promising. Impactful policy instruments in the early stage are the investment in research, providing subsidies for demonstration projects, public procurement, articulating visions that provide guidance, facilitating knowledge sharing between projects, supporting the creation of innovation networks, and reducing barriers for new actors [3].

This study analyzes the different analytical levels related to agrivoltaics, identifies the interests of relevant stakeholders, asses the governmental support, and draws lessons learned for Japan that are also helpful for countries aiming to advance agrivoltaics.

2. Methodology

Geels et al. [2, 4]’s analytical framework to evaluate the socio-technical dynamics of low carbon transitions is applied to analyze the dynamics of agrivoltaics in Japan over the last two decades. The analysis is based on various data sources. Academic publications, governmental reports, statistical data, and information by prefectural and municipal governments are used for the initial description. Subsequently, expert interviews were conducted to gain a deeper understanding of topics that are insufficiently covered by the currently available sources. Therefore, three interviews with farmers that already implemented agrivoltaics, one interview with a CEO of an electricity generation business, and three interviews with staff members of the Ministry of Agriculture, Forestry and Fishery (MAFF), the Ministry of Economy, Trade and Industry (METI), and the Ministry of Environment (MOE) were conducted in March 2023. The interviews ranged between 40 minutes and two hours and, except for one interview, were conducted in Japanese. Afterward, the interviews were transcribed and a qualitative content analysis was conducted. A limitation of the study is the relatively small sample size of seven interviews. Future studies should also include the positions of larger actors, such as institutional investors, utility-scale solar PV project developers, financial institutions, as well as farming and solar industry associations.

3. Results

After the first pilot project in 2004, agrivoltaics developed slowly in the following years in Japan. The advancement of agrivoltaics only started to accelerate in the early 2010s. All interview partners emphasized that the Fukushima nuclear disaster in March 2011, as an exogenous shock, changed their mindset alongside that of many other Japanese people. The need to reduce the reliance on nuclear power and increase the use of renewable energy motivated many to invest in solar photovoltaic (PV) projects, including agrivoltaics. Moreover, the introduction of generous Feed-In Tariffs (FIT) in 2012 and the allowance to install agrivoltaics on all farmland under certain requirements in 2013 provided the necessary policy support for a faster expansion.

Agrivoltaics spread quickly to 46 out of 47 prefectures in Japan [5]. A total of 3,474 agrivoltaics projects were permitted by 2020. The highest number of new permits (779) per year was approved in 2020 [6]. The vast majority of agrivoltaics are small-scale with 97% of the projects being under one hectare. The average size of permitted agrivoltaics by 2020 is only 0.25 hectares. The crop choice is diverse with more than 120 different types being cultivated in agrivoltaics systems in Japan. Vegetables account for a share of 35%, ornamental plants (e.g., Japanese cleyera) account for 30%, and fruits for another 14%. Almost 60% of farmers changed the crop type after installing agrivoltaics on their farmland suggesting that the crops are being deliberatively selected for growing under solar panels [7].

3.1 Japanese Context

It is necessary to recognize the unique Japanese context to understand the role of agrivoltaics. Only 34% of the land area is flat in Japan, compared to, for example, 69% in Germany or even 88% in the UK. Accordingly, the land use conflict for suitable land is high in Japan. The climatic conditions vary widely in the country which stretches more than 3000 km. Hokkaido in the north has subarctic weather conditions, whereas Okinawa in the far south is subtropical. The type of suitable agriculture differs consequently widely. Moreover, Japan lies on the Pacific Ring of Fire making the country vulnerable to geophysical natural hazards, such as earthquakes, tsunamis, and volcanic activity. Additionally, typhoons, heavy rain and snow events increase the risk of floods and landslides. Therefore, disaster resilience has a high priority for the Japanese government.

The agricultural sector in Japan is in a steep decline. The number of farmers decreased by one-third from two million to 1.3 million over the last decade. The trend is likely to continue if no suitable countermeasures are implemented since only 19% of the farmers are under 60 years [8]. The average age of a farmer in 2022 was 68.4 years [9]. The energy transition is still at an early stage in Japan. The share of renewable energy in Japan's electricity generation was 22.7% in 2022, which is only 0.3% higher than in the previous year. The share of solar PV accounted for 9.9% of the annual electricity generation [10]. The government aims to become carbon neutral by 2050. The renewable energy target for 2030 is set at 36-38% [11]. Overall, Japan is heavily dependent on imports in both the agricultural and energy sector. The food self-sufficiency ratio based on a calorie supply basis is 38% [12] and the energy self-sufficiency rate is only 12% [13].

3.2 Governmental Perspective

The national government and relevant ministries mention the need to promote agrivoltaics in recent key strategy papers. Agrivoltaics is referred to in the Follow-up on the Growth Strategy in 2019 and 2020 which is approved by the Cabinet Office and has a strong influence on future policies [14, 15], the Basic Energy Plan By METI, which provides guidance for the energy sector [11], and the Basic Plan for Food, Agriculture and Rural Areas by MAFF, which stipulates medium to long-term goals for the agricultural sector [12].

The ministries refer to agrivoltaics in the context of larger societal goals. In governmental documents and during the interviews with MAFF, METI, and MOE, the potential of agrivoltaics for (regional) decarbonization by increasing the share of renewable energy, revitalizing rural areas by providing additional income to farmers, increasing food and energy security by producing both electricity and agricultural products in the same area, and increasing disaster resilience by providing electricity in times of disaster and power outages was emphasized.

While the increasing horizontal policy integration on the national level [16] and the recognition that agrivoltaics can help to ease pressing societal problems is positive, agrivoltaics is only mentioned very briefly in the above-mentioned key strategy papers. A concrete vision and specific numerical targets for agrivoltaics are still missing. To establish such a vision and targets based on scientific evidence, further analyses of the area, technical and economic-feasible potential of agrivoltaics in Japan are necessary. The government should facilitate research since knowledge in these areas is still inadequate (*see Section 3.4*).

3.3 Legal Framework

The Ministry of Agriculture, Forestry and Fishery issued a directive on agrivoltaics in March 2013 that made it possible for agrivoltaics to be installed on all types of farmlands if the poles of the mounting frame structure are approved for a temporary land use conversion to non-agricultural land by the local agricultural council [17]. The requirements for the land use conversions are: 1) The mounting structure is only temporary and easily removable. 2) The shading rate ensures enough sunlight for crop growth. 3) The panel height is at least 2 meters. 4) The agrivoltaics system shall not hinder agricultural practices in surrounding areas. 5) The yield reduction must be under 20% compared to the average yield in the region. In the first directive, the maximum permit duration was set as three years after which a re-permit is necessary. The farmer must in principle provide a report on the yearly agricultural production. The local agricultural councils will provide guidance for improvement if the yield reduction is over 20%. The farmer must show effort in improving the agricultural production or is ordered to remove the agrivoltaics system if the guidance is ignored. The actual execution of the sanctions is, however, questionable since it is uncertain if the directives by MAFF are enforceable in practice. According to MAFF, no agrivoltaics system has actually been removed so far. However, the uncertain conditions of the 20% yield reduction rule cause hesitation by farmers, investors, and financial institutions and are seen as a major barrier to the expansion of agrivoltaics according to the interviewed experts.

The MAFF extended the maximum permit duration to ten years in their second directive in May 2018 if 1) a farmer can demonstrate competence in agricultural practices, 2) the agrivoltaics system is installed on “devastated farmland” or 3) the system is installed on farmland type 2 or type 3, i.e., low-quality farmland [18]. The third directive in March 2021 waived the height requirements for vertical agrivoltaics and abolished the need for temporary land use conversion for agrivoltaics on devastated land [19].

The most influential law by METI was the introduction of the FIT Act in 2012. In the beginning, it provided installers of agrivoltaics projects with a generous rate of up to 42 JPY/kWh for their electricity for a maximum of 20 years. However, the rate declined to only 10 JPY/kWh for small-scale projects in 2022. The second amendment of the FIT Act in April 2022 provides preferential treatment for some agrivoltaics projects. Generally, small-scale solar PV projects (10-50kW) must allocate 30% of their electricity to regional use. However, this requirement is waived for agrivoltaics projects which received a land use conversion permit of 10 years and which can guarantee that electricity for regional use can be provided during times of disasters [20].

3.4 Knowledge Creation and Sharing

Knowledge creation and sharing are especially important in the emergence stage of new technologies. The Japanese process is unique compared to many other countries. Even though there are already thousands of projects and Japan has an above OECD average gross domestic spending on research [21], there are only very limited academic publications on agrivoltaics.

Most of the knowledge creation was achieved by learning by doing. Especially in the early stage, farmers often conducted experiential learning by building projects themselves after exchanging information about possible designs and materials with fellow farmers. On the plus side, the real impacts of projects were immediately visible without the typical delay of academic research. However, this trial-and-error approach is expensive, and highly motivated early adopters are necessary to be willing to take the risk. Moreover, systematic analysis of projects that can advance agrivoltaics more efficiently is lacking without the involvement of research institutes. Currently, there is still a lack of researchers focusing on agrivoltaics in Japan and those researchers who are involved are not coordinating their work enough with each other according to one of the interviewed farmers who is also involved in academic research. The isolated work focusing on specific aspects of agrivoltaics does not allow for a more holistic analysis. Furthermore, the sparse research is still not reaching the farmers fast enough.

However, activities to share knowledge about agrivoltaics are increasing in recent years. The number of facilitators that disseminate information is rising. The organizations range from non-profit organizations to business associations to a governmental division of MAFF. Activities vary from sharing best practice examples on websites to the invitation to site visits to share knowledge directly with relevant stakeholders. However, the information still mainly reaches actors that are already involved or strongly interested in agrivoltaics. It would be beneficial to reach a wider audience. This is especially important since negative narratives about agrivoltaics (e.g., visual impact on the landscape) are already starting to slowly emerge on social media.

3.5 Technological Change

The ongoing knowledge creation and sharing resulted in a change in the technological design of agrivoltaics over the last two decades. In the first stage, technological change was driven by early adopting farmers. The early projects were built in a simple Do-It-Yourself design. The emphasis was on designs that were affordable, and easy to build and maintain by the farmers themselves. The main material of the mounting frame structure, for example, were single pipes which were easily accessible in hardware stores.

With the scaling up of agrivoltaics after the introduction of supporting policy instruments in the early 2010s, a more industrial design that could withstand natural disasters began to spread. At this second stage of agrivoltaics, mounting frame manufacturers with experience from ground-mounted solar PV systems increasingly became involved in the technical design of agrivoltaics systems. During this stage, the interest of some stakeholders diverged with some focusing on maximizing electricity production whereas others continued to prioritize agricultural productivity in their designs.

The next stage that will possibly influence the design of agrivoltaics systems is the slowly growing electrification of the agricultural sector according to the interviewed farmers. Ideally, a joint development by diverse stakeholders from the agricultural and energy sector will lead to a suitable design incorporating solutions for the many different needs.

3.6 Business Landscape

The already described socio-technical landscape and dynamics significantly impacted the business landscape in the last decade. In the beginning, mainly farmers installed agrivoltaics projects themselves or in a close relationship with electricity producers in an experimental way. However, the introduction of supporting policy instruments in the early 2010s transformed agrivoltaics into an economically feasible business model. The generous FIT rates first mainly led to the installation of cheaper ground-mounted solar PV projects. However, the suitable areas for these kinds of solar PV projects quickly filled up due to the land constraints in Japan. In search of available areas for projects, electricity producers turned to agrivoltaics since it was a way to install solar PV on high-quality farmland which is prohibited for ground-mounted PV systems. The high FIT rates also allowed farmers to continue experimenting with agrivoltaics despite the higher investment costs. However, the share of installers of agrivoltaics projects increasingly shifts towards electricity producers who account for 73% of the project installations in 2020 [7].

Currently, there is a search for a new sustainable business model since the FIT declined to a rate that is not profitable anymore for agrivoltaics according to the interviewed farmers and business operator. Power Purchase Agreements (PPA) are discussed as a possible approach. However, there are still many barriers especially for agrivoltaics projects since small-scale farmers cannot easily commit to long-term contracts and large-scale electricity consumers prefer contracts with large-scale projects. It also has to be seen if agrivoltaics projects can compete against the prices of large-scale ground-mounted solar PV projects. A business model suitable for small-scale farmers who are struggling to make money with their agricultural activities alone would be crucial for the rural revitalization and the advancement of agrivoltaics which is mainly driven by small-scale actors in Japan. Further research on the economic feasibility of agrivoltaics post-FIT is necessary to provide evidence-based recommendations.

3.7 Social Acceptance

Generally, the market acceptance is still low for agrivoltaics in Japan. The low willingness to install agrivoltaics can partly be explained by the low economic incentive caused by the declining FIT rate, the lack of vision by the government which leads to uncertainty and makes it difficult to invest in long-term projects, and the worries regarding the 20% yield reduction rule. Moreover, the high number of aging farmers without successors makes it impossible for many to commit to twenty years of proper farming. However, some factors are likely to increase market acceptance in the coming years. The high electricity prices make self-consumption and PPAs more attractive. Generally, there is also an increasing demand for renewable energy by companies that aim to fulfill their decarbonization commitments. Furthermore, according to the interviewed farmers, a mindset shift towards a more sustainable agricultural sector is slowly developing, especially among organic farmers who want to become independent of fossil fuels.

The community acceptance of agrivoltaics in Japan is still not sufficiently analyzed. The interview partners have not yet experienced direct opposition from residents, but these few best practice cases are not generalizable to the wider agrivoltaics sector, and more research is necessary. The local authorities and interviewed ministries, however, perceive a high risk of increasing conflicts and bad practices which will likely have a negative impact on their support for agrivoltaics. It is crucial to reduce the uncertainty and promote projects that provide local benefits and provide early transparent communication starting from the planning process since the number of agrivoltaics will increase in the coming years and more people will be directly affected. A spread of a negative narrative of agrivoltaics would hinder the growth of agrivoltaics and lead to more opposition as is already the case for large-scale solar PV projects in Japan.

3.8 Rural Culture

The rural culture provides a challenge for the further diffusion of agrivoltaics in Japan according to one of the interviewed farmers. Many farmers are risk-averse and are not willing to take on uncertain challenges. They are mostly hesitant to accept new approaches from the outside. Generally, the rural community is rather closed to the outside and most farmers are reluctant to share information about their activities making it difficult to conduct research on a larger scale. Moreover, there is a strong emotional attachment to farmland in Japan. Many farmers are unwilling to rent their farmland to strangers or people from outside of the region. Farmland is often left abandoned if aging farmers retire without a suitable successor. The farmland abandonment rate already increased from 9 to over 12% between 2005 and 2015 [22]. Overall, there is a high entry barrier to the agricultural sector in general and agrivoltaics in specific for new actors and researchers.

4. Conclusion

Agrivoltaics emerged over twenty years ago as a niche technology in Japan. Since then, thousands of projects were built in all parts of Japan. The expansion of agrivoltaics is accelerating with the most permits per year being approved in 2020. Many stakeholders recognize the advantages of agrivoltaics in Japan. Farmers who struggle to earn enough money with agriculture can earn extra income, electricity producers can expand their available land for solar PV, and governments and ministries have an additional tool to solve societal goals, such as decarbonization, rural revitalization, food and energy security, and disaster resiliency.

However, agrivoltaics remains a niche technology in Japan. The vast majorities of projects are small-scale and only contribute under 1% of the total solar PV electricity generation [23]. To advance agrivoltaics from a niche technology it is recommended that 1) the national government creates a clear vision specifically for agrivoltaics to ensure relevant actors and encourages long-term investments, 2) the requirements for the temporary land use conversion should be reconsidered to reduce legal barriers, such as the 20% yield reduction rule, 3) research on agrivoltaics should be advanced and supported by the government to reduce uncertainty and provide the basis for scientific-based decision making, 4) new business models suitable for agrivoltaics need to be developed and supported by the legal framework, 5) a positive narrative focusing on the societal benefits of agrivoltaics must be shared early on and widely to avoid opposition, and 6) young farmers need to be attracted to stop the decline of the agricultural sector and who are likely more open to taking on new challenges, such as agrivoltaics.

Author contributions

Christian Doedt: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Validation, Writing – original draft, Writing – review & editing Makoto Tajima: Guidance, Data curation Tetsunari Iida: Supervision, Data curation, Funding acquisition

Competing interests

The authors declare no competing interests.

Funding

This work was supported by the Japan Fund for Global Environment.

Acknowledgement

We are grateful for Koko Mitoh who supported us with conducting and transcribing the interviews, and for the experts (Dr. Takeshi Magami, Mr. Masafumi Shigeie, Mr. Kei Kondo, Mr. Takafumi Suzue, and the staff members of the Ministry of Agriculture, Forestry and Fishery, Ministry of Economy, Trade and Industry and the Ministry of Environment), who provided us with valuable insights. Moreover, we want to thank the reviewers for providing valuable feedback.

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