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Transforming Risk Perception and Fostering Cooperatively the Agri- PhotoVoltaics Technology With Farmers in Five Countries

A Sociological Perspective From the REGACE (Crop Responsive Greenhouse Agriphotovoltaics System With CO2 Enrichment for Higher Yields) Project

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Abstract. The interaction between agricultural practitioners and innovative technologies has emerged as a critical area of inquiry in contemporary academic discourse. Disruptive advancements in agricultural technology—particularly in the domains of drone applications, artificial intelligence (AI), and agrivoltaics—present significant potential to address urgent environmental and energy-related challenges. However, the successful adoption and integration of these technologies are contingent upon robust processes of societal acceptance and comprehension, especially among farmers, who constitute the primary users and key stakeholders. The theory of disruptive innovation, initially conceptualized by Bower and Christensen in 1995, underscores the transformative capacity of novel technologies across various sectors. Nevertheless, the efficacy of such innovations is predicated on their seamless integration and acceptance by diverse stakeholder groups, including primary actors such as farmers and industry, as well as secondary entities with ancillary interests. For technological innovations to achieve their intended outcomes, they must be accompanied by authentic participatory processes that involve end-users from the initial stages. Within this framework, next-generation agriphotovoltaics greenhouses—which integrate photovoltaic systems with agricultural practices and enhance soil CO_2 enrichment—represent a pivotal solution for reconciling agricultural productivity with renewable energy generation. The WP6 of Regace Project. In this perspective, the WP6 of the REGACE project aimed, through the use of mixed qualitative, quantitative, and participatory methodologies, to investigate farming communities' perceptions of agriphotovoltaics innovations. These sociological processes are intended to accompany the phases and models of agriphotovoltaics innovation from a perspective of social sustainability, with an active involvement of the community of innovation recipients.

Keywords: Agrivi Photovoltaics, Farmers Participation, Technology Co-Design

1. Introduction

The REGACE project aims to be an innovative and interdisciplinary initiative aimed at integrating technological advancements[1] with sociological inquiry within the emergent field of agrivoltaics. In response to the escalating climate crisis, agriphotovoltaics—defined as the strategic co-location of photovoltaic systems and agricultural activities—offers a promising pathway to address the dual imperatives of energy security and food security. This dual-use approach has the potential to optimize land utilization, augment renewable energy production, and sustain agricultural yields. Nevertheless, the widespread implementation of agriphotovoltaics remains constrained by a range of technological, economic, and social challenges, such as economic and social sustainability issues for technology takers.

The rationale for the REGACE project arises from the observation that, while signifi-cant progress has been made in the technological optimization of agriphotovoltaics systems, the social dimensions of their adoption have received comparatively less attention. The suc-cess of agriphotovoltaics innovations is contingent not solely upon their technical efficacy but equally upon their social acceptability and contextual feasibility. Existing literature tends to focus predominantly on technical performance metrics, neglecting the perceptions, concerns, and needs of farming communities, which are critical to the effective diffusion of these technologies. This neglect represents a notable gap in the existing body of knowledge, posing a significant barrier to the broader uptake of agriphotovoltaics systems.

The central objective of the REGACE project is to bridge this gap by examining the perceptions of farming communities towards agriphotovoltaics innovations and identifying the factors that facilitate or impede their adoption. The primary research questions guiding this investigation were: How do farming communities perceive agriphotovoltaics technologies, and what socio-cultural, economic, and practical factors influence their acceptance and integra-tion into agricultural practices[2]? By addressing this question, the project aims to contribute to a more nuanced understanding of the social dynamics underlying the adoption of agriphoto-voltaics systems, thereby informing and creating more effective and socially attuned imple-mentation strategies[3].

In this perspective of blending technological innovation and social consciousness through participatory methodologies, REGACE Project research advances existing scholar-ship by emphasizing the interplay between tech development and socio-cultural contexts. Furthermore, it underscores the necessity of incorporating participatory methodologies and stakeholder engagement into the innovation process to facilitate a socially conscious diffu-sion of new technologies. The project seeks to provide empirically grounded insights that will inform policy frameworks and best practices for promoting agriphotovoltaics systems, ensur-ing that these technologies are not only efficient and economically viable but also socially sus-tainable.

Within the broader discourse on agriphotovoltaics diffusion, the REGACE project highlights the importance of integrative approaches that align technological innovation with user-centric perspectives. By synthesizing advancements in system design with sociological insights, the project aspires to foster a resilient, sustainable, and widely accepted paradigm for dual-use land management, thus contributing meaningfully to the fields of renewable energy, sustaina-ble agriculture, and socio-technical systems research.

2. Methodology

A robust quanti-qualitative sociological methodology was designed and implemented for the WP6 REGACE project to systematically examine the perceptions, opinions, and attitudes of potential end-users toward agriphotovoltaics technologies[4]. The methodological approach sought to ensure the active participation of farming communities and relevant stakeholders in the co-design process, aligning technological innovation with user needs and expectations. This multi-method approach integrated in-depth interviews[5], focus groups[6,7,8], Open Space Technology, and the World Café method[9,10], deployed sequentially to facilitate iterative engagement and collaborative reflection. The integration of Open Space Technology (OST) and the World Café methodology provides a comprehensive and adaptable framework for facilitating stakeholder engagement and collaborative exploration in the context of agriphotovoltaics (APV) systems. This combined approach allows for both spontaneous idea generation and structured dialogue, enhancing the depth and breadth of insights gathered from participants such as farmers, researchers, and technology developers.

In the initial phase, Open Space Technology (OST) enables participants to explore a central theme—such as the opportunities and challenges associated with APV adoption—through a self-organizing process. Participants are invited to propose discussion topics within the overarching theme, which are then used to form breakout sessions. This flexible, participant-led format fosters creative exploration and allows diverse perspectives to emerge organically. Building on the themes identified in the OST phase, the subsequent World Café sessions introduce a more structured dialogic approach to deepen the exploration of specific issues. The World Café format involves rotating small-group discussions focused on targeted questions derived from the OST findings. Each table is facilitated by a host who maintains the continuity of the conversation and synthesizes key points as participants rotate. The use of visual tools such as concept maps, thematic cards, and flip charts enhances the recording and sharing of insights. This integrated methodology allows for a multilayered discussion process: the flexibility and spontaneity of OST encourage the broad identification of themes and ideas, while the structured nature of the World Café enables participants to refine and elaborate on these themes in greater detail. By conducting these sessions at multiple intervals throughout the year, the approach also captures seasonal variations in the risks, opportunities, and operational challenges associated with APV systems.

2.1 Participants Selection and Recruitment for Interviews and Participatory Sessions

A total of 44 in-depth interviews were conducted across the five countries partners of the REGACE Project: Italy, Austria, Germany, Israel, and Greece. These countries were strategically selected to encompass diverse agro-climatic conditions, farming systems, and socio-economic contexts, thus enhancing the generalizability of the findings. The rationale for selecting these countries -besides being partners of the REGACE Project - also reflects their varying levels of engagement with agriphotovoltaics initiatives and policies promoting renewable energy in agriculture.

Participants were identified through a combination of purposive sampling and snowball sampling techniques. Initial recruitment was facilitated through partnerships with farming associations, cooperatives, and agriphotovoltaics pilot projects, which enabled access to a broad spectrum of potential respondents. The selection criteria for participants included different patterns such as:

1. Type of Farming: A range of agricultural practices, including viticulture, horticulture, cereal cultivation, flowers, biologic and mixed farming, to capture diverse perspectives.

2. Farm Size: Inclusion of both small-scale farms and medium to large-scale farms to ensure representation across different scales of agricultural production.

3. Experience with Technology: Farmers with varying levels of exposure to agricultural innovations, including those unfamiliar with agriphotovoltaics systems, to provide a bal anced perspective.

4. Geographical Diversity: Participants from distinct regions within each country to reflect local variations in agricultural practices, infrastructural support, and policy frameworks.

5. Social and economic diversity: Participants from different social, religious and ethnic backgrounds were considered in the sample for in-depth interviews and participatory sessions in order to reflect the socially most diversified perspective of stakeholders' groups.

2.2 Development of the Interview Guide

The interview guide was developed based on an extensive review of the existing literature on agrivoltaics, stakeholder engagement, and participatory innovation processes. The guide comprised semi-structured, open-ended questions designed to explore key thematic areas:

1. Current Agricultural Practices: Types of crops cultivated, farming techniques employed, and resource management strategies.

2. Technological Awareness: Familiarity with agriphotovoltaics systems and other renewable energy technologies.

3. Perceived Barriers and Opportunities: Identification of challenges, economic considerations, and potential benefits related to agriphotovoltaics adoption.

4. Social Acceptability: Perceptions of agriphotovoltaics technology's impact on farming identity, community relations, and cultural practices.

5. Co-Design Preferences: Willingness to engage in participatory design processes and suggestions for aligning innovations with agricultural needs.

6. Sustainability Concerns: Insights into environmental, economic, and social sustainability issues associated with agriphotovoltaics deployment.

Interviews, conducted in participants' native languages (with the participation of trained social researchers), ranged from 30 to 50 minutes in duration. All interviews were audio-recorded, transcribed verbatim, and subjected to thematic analysis to identify patterns, relationships, and divergences in participant responses.

2.3 Participatory Sessions Design

To complement the individual interviews, the project employed participatory sessions with a combined mixed technique uniting Open Space Technology sessions and World Café rounds (each one with 8-15 participants), to facilitate deeper levels of farmers engagement and collaborative dialogue. This specific mix of informative and participatory techniques was selected for its inner capacity to promote egalitarian, inclusive and dynamic discussions. The World Café method, in particular, after giving robust scientific information to the participants via the technological partners of the Project, utilized structured dialogues and visual tools such as concept maps to explore themes related to agriphotovoltaics opportunities, challenges, and future directions.

2.3.1 Diversity in Participant Characteristics

The participatory sessions exhibited a wide range of demographic and professional characteristics, ensuring a nuanced understanding of involved farmers perspectives:

- Age Range: Participants ranged from 20 to over 65 years.
- Farm Types: Included vineyards, flowers, cereal farms, vegetable farms, flowers farming, organic and biological farming and mixed-use agriculture.
- Farm Sizes: Ranged from small-scale farms to medium scale farming plants

2.3.2 Ensuring Methodological Rigor

Several methodological measures were employed to ensure the rigor and validity of the research process:

1. Triangulation: Data from interviews and participatory techniques were cross-referenced to enhance the robustness of findings.
2. Member Checking: Preliminary findings were shared with participants to confirm the accuracy and credibility of interpretations.

This comprehensive methodological approach enabled the REGACE project to capture not only the perceptions of farmers as end-users involved in the activities of the REGACE Project but also to foster their active involvement in the co-design of agriphotovoltaics innovations. In this perspective every participatory methodology was meant to anticipate potential challenges and to align technological development with user-driven needs and expectations. Furthermore, we were able to better understand the underlying behavioural mechanisms that shape farmers' engagement with technological innovations. By actively involving participants in the co-construction of agriphotovoltaics technologies, the project identified potential challenges and generated shared anticipatory solutions, ensuring that the innovations developed are both technologically viable and socially sustainable.

3. Project Activities, Findings and Discussion

3.1. From the First Year Activity to the initial Findings of the Project

During the first year of the REGACE project (2023), several key activities were undertaken to engage farmers and collect data pertinent to the sociological analysis of agriphotovoltaics adoption. From February 2023 to March 2024, various initiatives were implemented in order to detect and analyse the perspectives of farmers on agriphotovoltaics. The following sections are dedicated only to the first year of activity and intend to sketch the outcomes of the on the ground research, which is summarized in the table below.

Table 1. *On the ground research activities by the WP6 of the REGACE Project.*

TIMING	ACTIVITY	AIM OF THE ACTIVITY	RESULTS
May 2023	International sociologica training center	training for scientific support for the on the ground activities in the 5 state partners	9 trained partners involved in the following 2 years activities of the Project
July - December 2023	44 in depth interview with defined sample of farmers in the 5 State partners (Austria, Germany, Greece, Israel, Italy)	in depth understanding of farmers' perception on PV and APV	detection of general a positive attitude towards the APV innovation; analysis of the main risks and opportunities
Jan - May 2024	2 world cafés (Germany, Italy)	participatory sessions with mixed techniques (Information about the REGACE Project Technology + OST, World Café; fishbowl as participatory restitution of the activity)	detailed analysis of the perception ot the new APV technology, of its opportunities and risks, of the pre-conditions for adopting and using it in everyday farming

Source: Authors' elaboration

The insights derived from in-depth interviews and the participatory sessions reveal nuanced perspectives on the adoption and implementation of agriphotovoltaics systems. Notably, there exists a prevailing positive attitude toward agriphotovoltaics in the involved community of farmers, reflecting an increasing awareness of its potential to synergize agricultural productivity with sustainable energy generation. This acceptance, however, seems contingent upon the systems' adaptability to specific local contexts and infrastructures, acknowledging the heterogeneity of regional agricultural practices and environmental conditions.

Figure 1. *Participatory Session in Italy - World Café setting*

Despite the perceived benefits, stakeholders articulated significant concern regarding the potentially high initial capital investments on the plant and the complexities associated with system maintenance. These concerns underscore the imperative for comprehensive full-service contracts encompassing rigorous initial farm due diligence, operator training, regular maintenance, and system updates to ensure long-term viability and efficiency. Moreover, the integration of agriphotovoltaics is anticipated to necessitate modifications to existing agricultural methodologies, highlighting the need for flexible practices that can accommodate such innovations. Beyond the immediate agronomic advantages, participants also identified broader social and economic benefits, including enhanced community energy resilience and diversified income streams for their farming activities To facilitate successful adoption of the APV plant, the need for sustained training and ongoing technical support was consistently emphasized - both in the interviews and in the participatory sessions, ensuring that farmers possess the requisite knowledge and skills to optimize these systems. Collectively, the first year findings underscore the necessity of a holistic, context-sensitive approach to agriphotovoltaics implementation that addresses both the technological intricacies and the socio-economic dynamics of rural communities.

3.2 Discussion

The first-year findings of the REGACE project reveal a generally positive attitude among farmers toward agriphotovoltaics (APV) systems and sustainable practices, with minimal variance across geographical regions. While farmers express openness to adopting advanced technologies such as AI, robotics, and automation to enhance efficiency, significant barriers undermine the potential for widespread adoption of APV. The primary obstacles are economic constraints—notably high initial investment costs and uncertain returns on investment—and managerial challenges that necessitate continuous training, technical assistance, and specialized insurance coverage. These burdens pose a considerable risk, particularly for small to medium-scale farmers who often lack the resources to manage such complexity.

Besides, regulatory and bureaucratic hurdles, including grid integration and licensing processes, can create further complications, highlighting systemic issues within agricultural policy frameworks. These barriers are not merely technical but reflect deeper misalignments between policy support and the realities of agricultural practice. Without substantial reforms on the laws and policies on power grids, APV adoption risks being limited to well-resourced farmers, in centrally served areas, with the risk of exacerbating inequalities within the agricultural sector.

Despite these challenges, there are promising opportunities for enhancing APV's feasibility, such as integrating APV systems with irrigation infrastructure, applying precision agriculture models, and establishing local level energy communities for shared benefits. However, the effectiveness of these solutions is contingent upon addressing the structural barriers identified on the specific law and policy arenas.

Crucially, the current findings are drawn from a limited in-depth analysis sample size. To fully understand the scope of these challenges and opportunities, large-scale surveys, encompassing a broader farmer population's attitude, may be useful in order to set a general perception scheme on the APV technology.

4. Conclusions and Future Perspectives

The first-year findings of the REGACE project yield significant insights into the multifaceted factors influencing the adoption of agriphotovoltaics (APV) systems within diverse farming communities. Data obtained through in-depth interviews and participatory world café sessions indicate a predominant openness toward APV technologies, reflecting an increasing cognizance of their potential to concurrently enhance agricultural productivity and renewable energy generation. However, this generally positive disposition is conditional upon several critical factors. The heterogeneity of regional agricultural practices, environmental conditions, and infrastructural capacities necessitates that APV systems be contextually adapted to specific localities to ensure practical applicability and operational efficiency.

Economic constraints emerge as a primary obstacle, particularly the substantial initial capital investment required for APV system installation, coupled with the ongoing complexities of system maintenance. These financial burdens underscore the imperative for the provision of comprehensive support mechanisms, including detailed farm-level due diligence, operator training, systematic maintenance schedules, and periodic technological updates. Such measures are essential to ensure the long-term viability and efficacy of APV systems, mitigating the risks associated with their integration into existing agricultural operations.

Furthermore, the findings underscore the necessity for sustained technical assistance and continuous capacity-building initiatives. The dynamic nature of APV technologies demands that farmers be equipped with advanced knowledge and skills to optimize system performance and adapt to evolving technological advancements. Beyond agronomic benefits, APV systems offer broader socio-economic advantages, such as enhancing community energy resilience and diversifying income streams, thereby contributing to the socioeconomic stability and development of rural areas.

Despite these promising opportunities, systemic barriers impede widespread APV adoption. Regulatory and bureaucratic challenges, particularly those related to grid integration and licensing procedures, reveal a misalignment between existing policy frameworks and the practical realities of agricultural enterprises. These structural impediments disproportionately affect small and medium-sized farmers, exacerbating existing socio-economic disparities and limiting the democratization of APV technology. Addressing these challenges requires substantive policy reforms aimed at streamlining regulatory processes, facilitating grid connectivity, and providing targeted financial incentives to support economically vulnerable farming operations.

Potential avenues for enhancing the feasibility of APV adoption include the integration of APV systems with existing irrigation infrastructure, the application of precision agriculture methodologies, and the establishment of local energy communities to promote equitable distribution of benefits. However, the efficacy of these strategies remains contingent upon the resolution of structural and regulatory barriers. Given the limited scope of the initial qualitative analysis, future research should encompass large-scale quantitative surveys to capture a broader and more representative sample of farmer perspectives. Such an expansion of the dataset would enable the development of a comprehensive analytical framework to inform evidence-based policy interventions and support mechanisms.

In conclusion, the first-year findings highlight the critical need for a holistic, context-sensitive approach to APV implementation. This approach must integrate technological, economic, and socio-political considerations to facilitate the successful adoption and sustainable deployment of APV systems, ensuring that their benefits are equitably distributed, and their potential fully realized within diverse agricultural contexts

Data availability statement

The article is not based on quantitative data but on the analysis of farmers' participation processes. For this reason, we state that they are not available both for reasons of privacy of the farmers who participated in the processes and because they would not add additional knowledge to the text of the article

Underlying and related material

We don’t have any underlying and related material

Author contributions

Maria Cristina Antonucci Conceptualization/Investigation/ Methodology/Writing – original draft

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Marco Serra Investigation/ Methodology

Cristina Cornaro Funding acquisition/Supervision

Marcello Petitta Conceptualization

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Competing interests

“The authors declare that they have no competing interests.”

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