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Abstract

Adopting agrophotovoltaic (AgroPV) systems involves many challenges, not only technical issues but also social and institutional challenges underlying insufficient social acceptance and institutional support. Using semi-structured interviews with the pioneer farmers, we explore the social and institutional challenges that may arise in implementing AgroPV systems in a developing country context—Turkiye—where there is currently no legislation on AgroPV. Still, the synergistic impact of AgroPV is highly probably due to climatic conditions in the Mediterranean setting. The pioneer farmers exhibit a highly positive attitude towards AgroPV systems reflecting that they recognize and highly value this synergistic potential. In particular, they are perceptive about how they may use AgroPV techniques to solve local problems, including those exacerbated by input dependency and climate change, beyond an abstract (economic or financial) opportunity dimension. In other words, there is a strong motivational drive for AgroPV given the challenges in Turkish agriculture; however, the weak institutional setting may channel farmers away from its adoption. Our interviews reveal that the institutional setting undermines predictability, which is vital in farmers' willingness and ability to participate in long-term, capital-intensive projects such as Agrivoltaics. Bureaucracy's distrust of potential investors, probably caused by low procedural capacity, seems to have bred a negative official attitude towards 'dual-use' innovations. This problem, in return, explains farmers' negative experiences, such as red tape in receiving licenses and permits, contributing to their doubts about sustained government support. Understanding this institutional setting is crucial for overcoming the bias towards developed countries in the literature and providing a more informed perspective before further legislative changes.

Keywords: Agrivoltaics; solar energy; dual land use; agriculture; institutions; energy policy
JEL Classifications: Q18, Q42, Q01

1. Introduction

About 30% of the world's energy is consumed within agri-food systems, which are responsible for a third of greenhouse emissions. Both food and energy systems must be transformed "to meet current and future demand for food and energy in a fair, environmentally sustainable, and inclusive

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manner" (IRENA and FAO 2021). However, using renewable energy in alignment with goals on climate change and sustainable development has significant implications for land use. Increased utilization of renewable energy sources may compete with other uses of land, including agricultural use. Agrophotovoltaic systems (AgroPV), as dual land-use systems where crop and livestock production continue in between or below photovoltaic panels, may address this problem by combining the production of solar energy and food. Yet, adopting AgroPV systems involves many challenges, not only technical issues such as identifying crops, plant design, and scale that satisfy the techno-economic viability of the system but also social and institutional challenges underlying insufficient social acceptance and institutional support. For successful implementation of AgroPV systems, we need research that explores these challenges so that they can be addressed through legal and institutional changes as well as complementary social and economic policies. This study aims to contribute to our understanding of the social and institutional challenges that may arise in implementing AgroPV systems in a developing country context—Turkiye—where there is currently no legislation related to AgroPV systems. Potential benefits of AgroPV are highly promising due to various natural (i.e., climatic) and economic factors in the agriculture sector. Therefore, the study starts with the premise that understanding the peculiar challenges and needs in Turkish agriculture (and how the Turkish farmers perceive AgroPV as a solution to them) is key to addressing social and institutional challenges. Thus, we embrace a holistic approach to examine the opportunities and challenges of AgroPV systems through qualitative research (in-depth semi-structured interviews) with farmers. Exploring both 'opportunities' and 'challenges' from the perspective of farmers is essential, not only because of the current troubles of agriculture in Turkiye but also because their 'motivating concerns' can guide policymakers and investors in how they tailor the legal framework and incentive structure.

Most studies on AgroPV systems have focused on developed-country contexts where agricultural land is relatively scarce, the population is dense, and photovoltaic energy production has expanded enough to create intense 'pressures' on land use changes. Accordingly, as the primary benefit of AgroPV systems, many studies have emphasized that they mitigate land use competition, particularly in regions where agricultural land is scarce, and the population is dense (Dupraz et al., 2011; Dinesh and Pearce, 2016; Hassanpour Adeh et al., 2018, 2019; Weselek 2019; Ketzer et al. 2020; Tromsdorff et al. 2021; Ressar et al., 2021). Yet, in some countries, recent research has revealed that the expansion of AgroPV systems has been motivated by other concerns, such as the increasing amount of devastated and abandoned farmland that farmers may reclaim through profitable AgroPV projects (Tajima and Lida, 2021). In the Turkish case, as we will explain in detail below, land use competition due to renewable energy production is not yet a significant issue.[2] However, the Turkish agricultural sector is faced with several challenges that put national food security at risk. Some of these challenges may be addressed by the synergistic use of land through AgroPV systems. In particular, increasing costs due to rising input prices, uncertainty due to fluctuations in global agricultural markets, and lack of agricultural planning have been major issues. As a result, agriculture has become a highly risky business, especially for small and middle-sized farmers who have historically constituted the majority of agricultural producers in the country.

[2] If new and more ambitious renewable energy targets are set in line with Turkiye's Green Deal process (which accelerated after Turkish government signed the Paris Agreement in 2021), this type of competition may soon become an important issue.

Furthermore, Turkish agriculture is prone to high production and income risks due to climate change and environmental hazards such as decreasing soil quality and erosion. If AgroPV systems could address some of these critical problems in Turkish agriculture,[3] it would serve not only renewable energy production but also the sustainability of agriculture. In fact, our findings suggest farmers' attitudes towards AgroPV systems are manifestations of adaptability to local problems, including those caused by climate change, besides the curiosity and (economic or financial) opportunity dimension.

This research is related to two strands of literature. First, there is a recent and flourishing literature on the potential opportunities and challenges of AgroPV adoption based on stakeholders' perceptions of this technology (Moore et al., 2021, 2022; Ketzer et al., 2020, Pascaris et al., 2020, 2021, Ressar et al. 2020, Trommsdorf et al. 2021).[4] In their analyses of stakeholders' perceptions, most studies have pointed to legislative and institutional barriers' role in agrivoltaics sector development. Our study builds upon this literature and reveals a peculiar aspect of AgroPV diffusion that seems crucial in the Turkish context: Our interviews indicate that institutional setting undermines predictability, which is vital in farmers' willingness and ability to participate in capital-intensive projects such as Agrovoltaics. Bureaucracy's distrust of potential investors, probably caused by low procedural capacity, seems to have bred a negative official attitude towards 'dual-use' innovations. This problem, in return, explains farmers' negative experiences, such as red tape in receiving licenses and permits, contributing to their doubts about sustained government support. Understanding this institutional setting is crucial for overcoming the bias towards developed countries in the literature and providing a more informed perspective before further legislative changes. Among opportunities, on the other hand, becoming more self-dependent in energy needs and exploring potential opportunities due to 'synergistic' impact seem to be the most prominent factors in farmers' favorable perceptions of AgroPV systems. In order to increase farmers' adoption of AgroPV systems, the government should introduce legislative changes and financial support mechanisms that facilitate investments, particularly those targeting self-use and/or local consumption. At the same time, creating regulations and incentives that align financial gains from energy sales to the grid with 'agricultural needs and purposes' will help alleviate mutual distrust.

In the first part of this paper, we provide a brief overview of the major characteristics of Turkish agriculture with a particular focus on the aspects that seem to relate to opportunities and challenges in farmers' adoption of AgroPV systems. These aspects (i.e., uncertainty, climate change, water-energy nexus, and renewable energy legislation) are identified based on recent research on Turkish agriculture and a preliminary assessment of our interviews. Then, in the second part, we present our methodology and explain the choices underlying our sample and questions. In the third part, we present our findings by summarizing common themes that came up repeatedly in the interviews, also identifying how these themes reflect and relate to farmers' perceptions about broader challenges in agriculture. Lastly, we conclude by summarizing our insights and implications for further research.

2. Country Context: The Characteristics of Turkish Agriculture and Solar Energy Sectors

[3] There are three studies on potential of AgroPV systems in Turkey. Coşgun (2021a) and Coşgun (2021b) uses merely 'solar radiation' data to point to the 'high potential' of AgroPV systems in Turkiye. Turan (2021) discusses potential benefits of AgroPV systems by referring to some problems such as erosion in Turkey.

[4] For a recent and comprehensive review of the AgroPV literature, see Vorast (2022).

In the last 20 years, Turkish agriculture grew by 2.3% annually between 2000 and 2021, with a total factor productivity growth of about 44 % in the sector (USDA, 2022). Various studies attributed this growth to agricultural intensification and increased use of inputs (Atiyas and Bakıs¸ 2013; Özden, 2014; Eruygur et al., 2016). Yet, Turkish agriculture has also been troubled with structural problems such as small farm size, rising input costs, and depletion of natural resources, including soil quality.[5] These structural problems, coupled with climate change and policy challenges, have already led to concerns about the sustainability of agricultural production and food security (TUSIAD 2020, Yıldırım 2020).

Since the liberalization of Turkish agriculture 20 years ago, production has been highly volatile with rapidly changing crop patterns. Most importantly, there has been a shift from major crops such as wheat and corn towards relatively high-value-added fruits and vegetables (Yıldırım 2022: 112-114). While these changes provided farmers with opportunities for higher income, lack of planning also made them vulnerable to market fluctuations. An increase in the price of a particular crop encourages many farmers to switch to planting that crop in one year, leading to excess supply and a resulting decrease in its price in the following (Yıldırım, 2022: 113). In fact, the income risks that this lack of planning posed for farmers' livelihood and the stability of the food supply have been acknowledged as major shortcomings by both policymakers and researchers.[6] More recently, disruptions in international trade due to wars and pandemics have posed further challenges to stability in agricultural markets. Yet, the government policy has been mostly reactive, with little consideration for the long-term agricultural supply. Given these unfavorable conditions, many farmers have exited farming or plan to do so (Berk 2018, Yılmaz et al. 2020).[7] At the same time, urban sprawl and the rise of highly profitable sectors such as energy, mining, and construction have caused changes in land use. As a result of these developments, the total agricultural area has decreased by 8% since the early 2000s (TUIK, 2020a).

In addition to the structural problems in the agriculture sector, climate change and human-induced factors have put severe pressure on soil and water resources in Turkiye (WB, 2022). The erosion rate is twice the world average (Erol et al., 2009; Demir et al., 2017), and the quantity of organic matter is considered deficient in most of the arable land (ÇEM, 2018). Practices such as intensive tillage and faulty irrigation have accelerated erosion and caused salinization, leading to soil loss and deteriorating soil quality (WWF, 2021). According to a recent study, 32% of the land will soon be at high risk of degradation and desertification (Uzuner and Dengiz 2020), which may cause a long-term decrease in agricultural productivity.

With climate change, drought has already become a severe problem, especially in the central, southern, and southeastern regions (Şahin and Kurnaz, 2014). The future climate projections

[5] For a comprehensive overview of Turkish agriculture, see TUSIAD Report 2020 and Yeni and Teoman (2022).

[6] Acknowledging these problems, the Turkish Ministry of Agriculture introduced a Basin-Based Agricultural Support System in 2010, where supports were made conditional upon 'crop choice' being made in line with the geographical and climatic conditions of each region. Yet, the system could not be implemented for problems in policy landscape (Yıldırım, 2022). More recently, the Minister of Agriculture stated that the Ministry will embrace a planning perspective and will not allow 'haphazardness' in agriculture (MAF, 2022).

[7] According to Social Security Registrations, in the last 12 years the number of farmers decreased from 1.016.692 to 475.953 (SGK, 2022). While this data has some problems, farmers' registry system also indicates a declining trend. In a recent study, almost 60 % of farmers stated that they would not recommend younger generations a livelihood in agriculture. (Yılmaz et. al. 2020)

indicate that temperatures will drastically rise and precipitation will decline in most regions, causing water scarcity. In addition to drought, extreme weather events such as excessive rain and hail will be more frequent (Dudu and Çakmak, 2018; WB, 2022). All these climatic changes are expected to cause significant yield losses (between %3.8% and 40%) in many crops until the 2050s (TUSIAD, 2020; Türkeş, 2020; Dudu and Çakmak, 2018, Dellal et al., 2011). In fact, in climate risk vulnerability indicators, Turkiye ranks top among OECD countries in the Mediterranean climate basin (See Table 1). The socio-economic factors that shape the agricultural structure, especially the small and medium-scale farms' limited capacity to respond, increase the vulnerability against climate risks. While farmers have already adopted some strategies to fight climate change, compensating to some extent for yield losses (Karapınar and Özertan 2020), it will be challenging to avert the decline in food production and the resulting rise in food prices without radical changes.

Table 1: Climate Risk Vulnerability in Türkiye and Other OECD-Mediterranean Countries

	Turkiye	**France**	**Greece**	**Italy**	**Spain**	**Portugal**	**Slovenia**	**Israel**
Agriculture, Forestry, and Fishing (% of GDP)	High	Medium	High	Medium	Medium	Medium	High	Low
Annual Extreme Heat Days Increase in 2050	High	Medium	High	Medium	High	High	Medium	High
Maize Yield Change in 2050	High	Medium	High	Medium	High	Medium	High	Medium
Share of population exposure in 2050	Medium	High	Low	Medium	Low	Medium	Low	Low

Source: World Bank (2022)

Climatic changes also force farmers to change crop patterns because of agronomic imperatives and increased costs. In many regions, irrigation costs increase as precipitation decreases and surface water becomes less reliable. For instance, in the Konya Karapınar region, many farmers dig deeper wells as current wells are at risk of running dry. But deeper wells are more expensive to construct and maintain (additional power is required to pump groundwater from greater depths (Öktem, 2016). Given these higher costs due to climate change, farmers are forced to choose either the cultivation of low-cost crops or those with substantial market opportunities (high-priced crops) at the expense of environmental damage (more water demanding, monoculture and conventional farming) (WWF, 2021). Therefore, to increase the resilience of the agricultural system, it is crucial for farmers to reduce input dependency and adopt practices and innovations that raise the water-holding capacity of the soil (Dudu, 2017).

In addition to crop and income losses, climate change has implications for water management and energy demand. Currently, only 19% of arable land is irrigated in Turkiye.[8] Yet, 74% of the underground and surface water is used in agriculture.[9] The most common form of irrigation is

[8] This area, amounting to 4,56 million hectares, corresponds to 54% of the 'arable land suitable for irrigation' (DSI 2021: 24).
[9] This ratio is around 1/3 in Europe. See MAF, National Patwhay Final Report (2021: 35).

uncontrolled surface irrigation.[10] With climate change, Turkiye is at high risk of water scarcity[11] , and conserving water resources has become a top priority. Accordingly, many policy documents underlined the expansion of controlled and climate-smart irrigation systems as a key target.[12] But irrigation based upon modern and digitized technologies and infrastructure requires irrigation motors and pumps and thus increases energy demand. Currently, most of the controlled irrigation in Turkiye depends on electricity and diesel fuel as primary energy sources. As the agricultural sector expands its electrification due to the modernization of irrigation infrastructure, there will be a higher energy demand. Energy is also a key resource for agricultural activities such as greenhouse heating, cooling systems in barns, storage, and processing operations.

In Turkiye, energy demand in agriculture is met mainly by fossil fuels such as diesel which has risen to the top among the cost items (Sayın et al., 2005). In the last year, diesel prices rose 236 %, while electricity prices rose 128 % (TUIK 2022), contributing significantly to the unprecedented cost inflation and spiking food prices. Turkiye has the highest food inflation among OECD countries (OECD-FAO, 2022).[13] Given rising food prices and the urgent need for energy transition, there is a higher interest in exploring and utilizing alternative energy sources.[14] Renewable energy, especially solar energy, as a clean and cost-efficient resource in agricultural production,[15] has come to the fore in the policy agenda.[16]

In short, solar energy is expected to play an important role in increasing energy and water efficiency in Turkiye. But, the current state of renewable energy legislation also has some bearing on the potential use of solar energy. Therefore, this part will briefly overview current renewable energy legislation focusing on solar energy use in agriculture. In Turkiye, the first legislation on solar energy was introduced in 2013. Shortly after, the first solar project with a capacity of 40 MW was launched. By the end of 2021, the sector had reached an installed capacity of about 7700 MW (TEIAŞ, 2021). While this is a remarkable increase in a short period, it is still far below 2023 targets estimated in accordance with the long-term goals of the energy transition (Şahin et al, 2021). Turkiye's energy system is still characterized by a large share of fossil fuels, which accounted for 83% of the total primary energy supply in 2019 (IEA, 2021).

[10] 61,1% of the areas irrigated by DSI are irrigated by surface methods, while the remaining area is irrigated by sprinkler (21.6%) and drip (17.3%) methods (DSI, 2021).

[11] As of now, 15 of 25 river basins in the country are at risk of water stress (WB, 2022).

[12] The reports of The Eleventh Development Plan (2019-2023) by Presidency of Strategy and Budget and Ministry of Agricultural and Forestry Strategic Plan: 2019-2023.

[13] According to the OECD-FAO Agricultural Outlook Report 2022-2031, food price inflation in Turkiye has been the highest among OECD countries in the last two years (18% in 2021 and 55% in 2022).

[14] Gopal et al. (2013) carry out a literature review on this topic, and there are also several studies of alternative energy sources for pumping water. See Bozord Haddad (2014), Bataineh (2016), Chandel et al. (2015) and Purohit and Kandpal (2005).

[15] A study on Turkish agriculture has revealed that the operation costs of pressurized irrigation systems using diesel oil are 4.5 times higher than irrigation systems operating with photovoltaic systems (Şenol, 2012).

[16] The Ministry of Agriculture and Forestry aimed to ensure the use of solar energy systems in order to reduce electricity costs in agricultural irrigation (MAF, 2021) and accordingly under "the Scope of Rural Development Supports," the government started to offer grants for solar energy investments for agricultural irrigation (No. 31406 Official Gazette in 25th Feb 2021).

There are various legal and institutional factors underlying the underdevelopment of the solar energy sector, some of which are also relevant for understanding barriers to solar energy use in agriculture. In order to incentivize renewable energy investments, Turkiye instituted various mechanisms, including 10-year feed-in-tariffs (FIT) under the support mechanism called YEKDEM. In addition to these tariffs, incentives such as connection priorities, reduced license fees, and various conveniences in land acquisition are available. More importantly, many of the solar projects are exempt from licensing requirements: Renewable projects with an installed capacity of a maximum of 5MW, except for ground-mounted solar projects, and self-consumption projects may be installed and operated without a generation license. In the last few years, more changes were introduced to enable energy generation in unlicensed projects and for own consumption needs.[17] Despite all these positive changes, certain challenges continue to limit investment in renewable energy projects, such as grid capacity limitations, burdensome permitting requirements, and uncertainties in the support mechanisms.[18]

Two other issues are particularly relevant for agricultural producers aiming to invest in solar energy generation for their use. First, the sale of electricity generated by license-exempt projects is prohibited. Second, there is organizational overlap and conflict in regulations concerning renewable energy investments on arable land. Renewable energy policies are formulated and implemented by the Ministry of Energy and Natural Resources (MENR). Yet, permits on arable land require approval from the Ministry of Agriculture and Forestry (MAF). The Soil Conservation and Land Use Act currently in force does not allow any construction on agricultural lands classified as 'productive'.[19] Based upon this law, the Directive on the Agricultural Land Conservation, Use, and Planning (Act No 30265) specified conditions under which renewable energy investments align with ‘land conservation law’ and may acquire permission from the MAF (Official Gazette, 2017). If the investor aims to establish a grid connection and sell electricity to the grid, the Energy Market Regulatory Authority should also approve the project.

To get a permit to build PV panels on agricultural land, the applicant should apply to the relevant planning institution with land registry documents and cadastral maps and then to the provincial directorate of the MAF. Based upon its digital database of agricultural land evaluation and *in situ* examination of the area, the directorate prepares a land survey report on the area’s “land class” and “land use” as well as its other agricultural characteristics and relations to surrounding land. If the report classifies the area as "marginal agricultural land" and establishes that its use for other purposes would not disturb the integrity of agricultural use or land consolidation projects in the surrounding areas, then the project is approved. No permit will be granted if the area is classified as any other type of agricultural land. These rules, along with others stated in the Directive, impose a large set of conditions for the non-agricultural use of agricultural land.

3. Methodology: Semi-Structured Interviews with Pioneer Farmers in Turkiye

For this research, we collected data through semi-structured interviews between June and October 2022. In total, we interviewed 16 farmers individually in face-to-face and online meetings. In

[17] In 2019, a new regulation regarding ‘unlicensed projects’ covering roof applications was introduced (Act No 30772, increasing tariffs and granting an additional 3-month period to unlicensed projects (Official Gazette, 2019). With the Renewable Energy Law introduced in 2020 (Act No 5346) service fees were reduced or cancelled as an incentive for those willing to build energy generation facilities to meet their own energy consumption needs (Official Gazette, 2020)
[18] For a discussion of political context underlying energy policy ambivalence, see (Bayulgen, 2013).
[19] Law of Land Conservation and Use, No. 5403 (Official Gazette, 2005).

addition, to make sense of specific ‘institutional’ and ‘legal’ issues mentioned by the interviewees, we communicated with the two government officials in the Ministry of Agriculture with expertise on solar energy legislation and acquired the draft ‘policy opinions’ on solar energy generation on agricultural land.

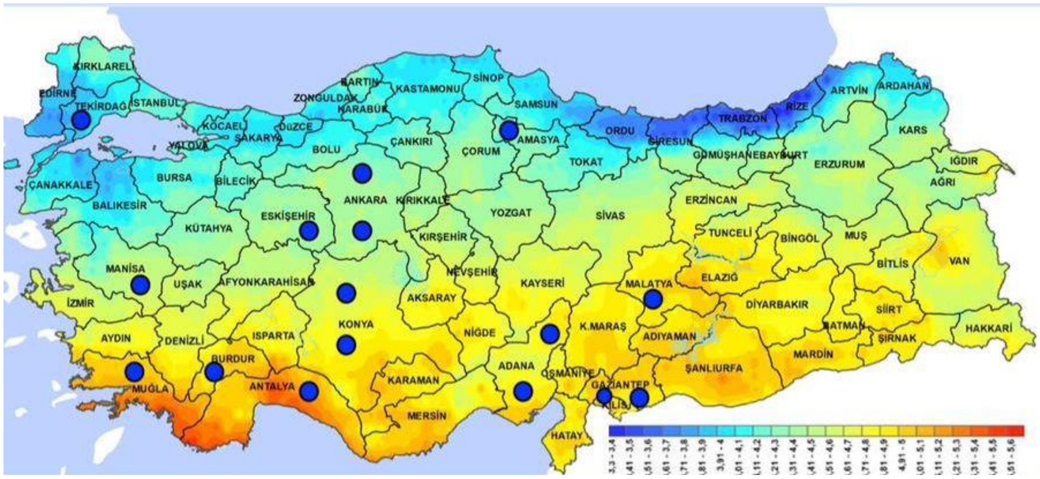
The interviews with farmers were semi-structured around a list of questions and themes. These questions and themes were based on our preliminary analysis of the AgroPV literature as well as secondary literature on Turkish agriculture. When choosing and adapting questions, we focused on gaining insight into how agriculture's socio-economic and institutional context may have implications for farmers’ adoption of AgroPV systems. We do not suggest that the farmers’ opinions indicate the problems that will undoubtedly emerge in the application case as AgroPV technologies are fast changing, and case-specific designs are introduced. In other words, our aim is not to provide a qualitative substitute for technical analysis (i.e., evaluating the costs and benefits of AgroPV systems). But an in-depth analysis of farmers’ opinions about AgroPV systems reveals how country-specific factors such as peculiar institutional and socio-economic uncertainties might contribute to the underutilization of these technologies.

We constructed our sample using both purposive and snowball sampling methods.[20] In accordance with our research topic, we decided to give precedence to the farmers who will be more likely to adopt new technologies in general. Therefore, we called upon experts in governmental and non-governmental organizations to identify “pioneer farmers,” farmers who are known by their peers as ‘willing to undertake new methods and approaches in farming.’ These farmers are probably more likely to be followed by others in knowledge and information dissemination (Fite, 1976; Ataei et al., 2019; Aksoy and Öz, 2020). They also have the knowledge and experience to offer useful insights on the topic. In fact, some of our interviewees are highly experienced in solar energy use for their agricultural practices (#5, #16). We also interviewed the farmer participating in the very first AgroPv project in Turkiye, which is currently being installed with a special permit from the government.

In selecting potential interviewees, we also considered that there might be climate- and crop-specific insights. Therefore, we aimed to include farmers from various regions with a wide range of natural conditions, such as degree of solar radiation, climate, and soil characteristics (See Figure 1). We interviewed farmers engaged in crop production and animal husbandry. The crop farmers also exhibit diversity in their main field of operation, including expertise in open field-annual crops, perennial vineyard/orchard gardens, and greenhouses. Lastly, they differ in terms of their farming methods, such as conventional agriculture, organic agriculture, and permaculture.

[20] While purposive sampling is utilized to include the experts who conform to knowledgeable characteristics (Tongco, 2008) to increase the heterogenity of the sample across geography, solar experience (Biggs et al, 2022) and also farmer methods and gender, snowball sampling is employed by gradually referring study participants to other potential contributors (Bryman, 2009)

Figure 1: Solar Radiation Distribution (kWs/m2/day) in Turkiye (2004-2021)



Source: Authors' information and Turkish State Meteorological Service

Table 2 summarizes the background information on the pioneer farmers we intervieweed: Most of them have 10+ years of experience in the field; many hold university degrees, while some hold graduate degrees.[21] These characteristics align with our choice to interview 'pioneer' farmers. Also four of our 16 interviewees are women. The farmers in our sample produce a wide range of agricultural products, including grains and cereals (chickpea, barley, wheat, corn, etc.); vegetables (eggplants, pepper, beet, lettuce, etc.) and fruits (tomatoes, grapes, nectarine, citrus, pear, apple, watermelon, melon, etc.); nuts (sunflower seeds, pistachios, almonds, etc.) and meat and dairy products. As a result of this variation, different agronomic concerns have come up depending on the crop type.

Table 2: Interviewee Background

[21]In a survey study on farmers in Izmir region, the average education of farmers was 7.5 years (Koyubenbe et al, 2010).

Interviewee ID	Gender	City	Age	Education	Years of Experience	Agriculture/Livestock	Product
1	Female	Burdur	38	Ph. D.	13	Agriculture/farm	Medical aromatic, chickpea and barley
2	Female	Manisa	65	University	10	Agriculture/vineyard	Table grapes, olives
3	Male	Eskişehir	60	University (Agricultural Engineer)	30	Agriculture/farm	Vegetables, walnuts, echinacea
4	Male	Konya	45	High School	30	Agriculture/farm	Sugar beet, grain corn, sunflower seeds for oil, wheat, barley
5	Male	Amasya	53	High School	24	Agriculture/farm-Cattle/Milk	Forage crops (corn, figs, peas)
6	Male	Tekirdağ	60	Primary School	45	Agriculture/farm/vineyard-Cattle	Wheat-barley-canola; Sunflower-corn-forage crops; melon watermelon
7	Male	Malatya	45	University (Lanscape Architect)	30	Agriculture/garden	Apricot
8	Male	Antalya	50	University	25	Agriculture/green house	Vegetables, citrus
9	Male	Kilis	50	Ph.D. in USA	35	Agriculture/farm	Pistachios, barley, chickpeas, lentils, alfalfa, corn cotton, olives, almonds
10	Male	Ankara	50	Primary School	35	Agriculture/farm	Wheat, chickpeas, sunflower seeds, silage and grain corn, pumpkin seeds
11	Male	Ankara	55	Secondary School	40	Agriculture/farm	Barley, wheat, corn, vetch, clover, tomato, pepper, eggplant
12	Male	Adana	52	Masters	27	Agriculture/farm-Cattle/Milk	Fodder and citrus
13	Female	Gaziantep	35	University	20	Agriculture/farm-Sheep	Pepper (for powder-chilli powder), wheat, beet, corn
14	Male	Konya	38	High School/University Student	21	Agriculture/farm-Cattle/Breeder	Beet, corn, sunflower (for oil and snack food), peas, lettuce, tomato.
15	Female	Adana	60	University	10	Agriculture/garden	Nectarine, citrus, pear, apple
16	Male	Muğla	51	High School	9	Agriculture/farm-Cattle/Milk	Feed (wheat, barley, silage maize)

4. The Qualitative Findings on AgroPV Potential

Almost all our interviewees (15 out of 16 farmers) expressed a positive opinion on AgroPV systems, i.e., when asked if they would be interested in investing in AgroPV systems on their land, they said "yes."[22] But, most of the positive answers were conditional upon some factors, such as acquiring more detailed information about the effects on crop agronomy and productivity and setup costs. Although the farmers had no experience with AgroPV systems, the content of their comments was very rich and revealed an experiential knowledge of most issues that are examined in academic research, such as the effects of AgroPV on crop agronomy, microclimate, and soil quality. These detailed comments probably reflect farmers' concerns about local challenges, including the adverse impact of climate change.[23] The first part summarizes the factors underlying our interviewees' positive opinions about AgroPV systems. The next part will outline the reasons underlying their reservations, i.e., why and when they think they would be more willing to invest in these systems.

[22] Only one interviewee stated that, he would not "hammer a nail, no matter what" because of rising costs and adverse government policies (#8) and one had a positive opinion about AgroPV but he did not think it was suitable for his farm (#16).

[23] Many of our interviewees noted their observations about how climate changes affected production. In a study on farmers in Northwestern Turkey, more than 90 % of farmers expressed that they were worried about climate change (Everest, 2021).

4. 1. Foreseen Benefits

i) Cost Savings – Almost all the interviewees have pointed to the high electricity costs as one of the most significant problems of agricultural production and viewed 'cost saving' as one of the most important potential benefits of building AgroPV on their farm. As we explained above, in Turkiye most of the ‘controlled' irrigation systems depend on electricity or diesel fuel. High electricity and fuel costs not only reduce irrigation and, thus, productivity but also force farmers to change their crop patterns or abandon agriculture altogether. In fact, when interviewees were asked about "the most important problems" in their agricultural production, most of them (#9, #14, #16 etc.) stated that energy costs (electricity and fuel costs) were the most troublesome. Some interviewees also indicated that they have already tried to find solutions to the problem of the high cost of electricity through investments in water-saving devices or renewable energy. For instance, one interviewee (#9) invested in an inverter pump that adapts electricity use to irrigation and thus reduced costs. However, he also mentioned that these pumps are relatively expensive and would not be affordable for most farmers. Another interviewee (#12) had recently built panels on the roof of his dairy farm, which reduced two-thirds of the costs of the total electricity used for air conditioning the cattle.

Cost-saving is also essential for farmers producing high-value-added crops and those with food processing plants using electricity. For instance, one of the interviewees (#1) was engaged in dry agriculture and used small amounts of water in irrigation. Yet, she produced herbs used in aromatic oil production in her own manufacturing workshops resulting in a very high cost of electricity for her business (we should note that the price of electricity is higher for industrial consumption, although such ‘industrial’ processes complement agricultural production). The producers in the surrounding regions also benefited from using these oil-producing machinery in return for a fee. The interviewee stated that if she could reduce her electricity costs, she might also be more like to charge a lower fee. Therefore, the cost-saving benefits of electricity generated by PV modules will be even more pronounced for sub-sectors integrating agricultural production with industrial processing.

The cost-saving might also be driven by water conservation if shading reduces evaporation. Interviewee #9 stated that if shading of the panels were to cause less evaporation from the soil, it might reduce the need for irrigation. He added that research on the effect of AgroPV systems on evaporation and the resulting amount of water conservation would be vital for farmers' decision-making.[24]

Another cost-saving item mentioned by interviewees (#1) is the labor cost saved for clearing weeds on land. As the panels partially cut the sunlight, fewer weeds might appear on land. It is also mentioned that as the solar panels keep the soil moisture, the natural balance of the soil could be maintained; because of that, there could be natural farming that needs less fertilizers and herbicides, so costs attached to these could fall (#2).

As interviewee #1 stated, another factor that may reduce the costs might be due to the effects of shading on the weed-crop competition. Environmental qualities, particularly in the crop ecosystem, affect various crop agronomic traits, including days to flower, canopy height and width, branching pattern, lodging, days to maturity, seed size, and yield. It has also implications for competition

[24] Various studies analyzed water use efficiency outcomes according to different climate and crop characteristics (Marrou et al, 2013, Elamri et al., 2018, Adeh et al, 2018, Amaducci et al, 2018, Patel et al, 2019).

among crops and weeds (Holt, 1995). The impact of shading on crop-weed competition and weed management has to be evaluated to establish AgroPV's cost-saving potential.

According to the interviewees, in livestock farming, as well, the cost-saving benefits of Agro-PV might be significant. The cooling systems of animals (such as sprinklers and fans), which is crucial for both productivity (heat stress is a major cause of diminished milk production in dairy cows) and animal welfare, require a lot of energy and water use. The electricity generated by PV modules on the common grassland or private livestock farms might reduce electricity costs (#12, #6). The electricity generated might also be used for cooling the milk storage (#6).

***ii) Positive Effects on Crop Productivity* –** Several interviews pointed out that the AgroPV panels might increase or sustain crop productivity for certain crops in extreme weather events. Panels can serve as a protective shield against extreme weather events such as extreme heat and hail (#12, #9). For instance, in the Southeast Region, the shading of the panels might contribute to the protection of crops against extreme heat, reduce evaporation, and thus contribute to sustaining productivity (#2, #15). If excessive heat coincides with the plant's flowering period, the flowers burn, and yield loss is experienced (#13). Some interviewees also named certain crops which they thought might have been more suitable for growing under panels. For instance, interviewees said they were faced with the risk of hail, and panels might be especially useful in crops such as apricots (#12, #9). An interviewee suggested that strawberries may be suitable because shading might not affect them much (#12). Another one (#1) said barley and chickpeas might be more appropriate to combine with a PV system. One interviewee (#9) indicated there should be research on the impact of shading on the growth of crops, such as clover, that require sufficient solar radiation but do not like high temperatures (#9).

Expert farmers' ideas on which crops may be more compatible with AgroPV systems reflect their guesses based on knowledge and experience with the growth of local produce rather than a technical agronomic analysis. Indeed, most interviewees indicated that the research and demonstrable "experiments" on how AgroPV panels affect crop growth and quality, as well as other aspects of production (such as weeds, mould, etc.), would be beneficial (#12, #9, #1, #6). As we mentioned above, there is an expanding literature connecting PV system design and/or shading analysis to field experiments.[25] Our interviews indicate that farmers need to access information regarding these agronomic aspects as the research builds up to provide an overview and orientation regarding which crop or agricultural activity may be best to combine with the PV system.

***iii) Income generation* –** Some interviewees suggested that if electricity generated by AgroPV is sold to the grid, it will generate an extra income that may be used to sustain or increase agricultural production. As we explain below, the grid connection and integration may involve cumbersome and costly processes, which may deter many farmers or potential investors. The monthly netting also might not be very favorable for farmers whose energy demand is particularly high during certain months (as interviewee 16 stated, the annual netting system would be more favorable for farmers as they would be able to 'use' extra energy they generated during low-activity months). But if the processes are not cumbersome, the income generation through netting might also be crucial in creating a cash flow to recover the project's initial investment. As one of the interviewees (#6)

[25] There is a strand of literature that focuses on how shading affects agronomic characteristics of the crops in various settings: Marrou et al, 2013; Elamri et al 2018; Thompson et al 2020; Weselek et al, 2021b, Barron-Gafford et al, 2019; Thompson et. al. 2020; Gonocruz et al, 2021.

stated, for the farmer-investors, estimations on how long it will take until cash flows (and cost savings) recover the initial investment of the project are essential. The latter, however, will depend on the 'feed-in tariff' of the electricity supplied to the grid as well as potential gains/losses in crop productivity.

It is also mentioned that when agricultural land generates electricity, it can increase the land price and the farmers' welfare. Although this is considered an opportunity for AgroPV use, it can also work both ways and make it more difficult for potential new farmers to buy land and start farming. Policymakers should favor new farmers in its land use policy.

iv) Environmental Benefits– When explicitly asked how AgroPV systems may impact the environment, all our interviewees expressed a favorable opinion. In addition, one interviewee (#8) mentioned that the electricity generated by AgroPV systems might enable the production of crops in places where they are not usually grown (through 'greenhouse' heating). As a result, the crops could be produced and consumed locally.

4. 2. Foreseen Drawbacks

i) Adverse Effects on Crop Productivity and Quality

Some interviewees expressed their concern about the potential effects of shading on pollination (#12). The crop's solar radiation requirements were considered an essential factor for AgroPV systems' impact on productivity and quality. For instance, an interviewee (#12) referred to 'strawberries' as potentially suitable crops because they grow more easily under shade. Another interviewee (#8) mentioned 'banana trees' as potentially appropriate because of their lower need for solar radiation while considering citrus trees 'unsuitable.' An interviewee pointed out that the heat difference between day and night is important for distinctive characteristics of certain crops that are important for their marketability: For instance, pistachios require excess heat during the day for 'crackling' (#9). If they do not hear the crackle, the farmer would need a machine for this process, which will constitute another cost. Likewise, tomatoes would require higher solar radiation to turn red (#9). Some interviewed mentioned shading may cause delays in the flowering and fructifying of the plants, which may have an implication for market prices, i.e., the crops harvested earlier and supplied first at the market are priced higher than later ones (#2, #15). Design of AgroPV systems that are flexible enough (i.e., rotating) to change the intensity of shading according to agronomic research might help optimize yields, plant growth, and agronomic qualities. Nevertheless, this flexibility will also imply higher costs that should be considered.

The adverse effects on yields may also occur through panels' impact on microclimate.[26] The possibility that the solar panels could block wind had been raised by some pioneer farmers we interviewed (#14, #16). As the wind is important for crop fertilization, it could be important to place solar panels such that the fertilization process will not be adversely affected. Also, although some livestock producers mentioned that animals feel much better in the shadow under the solar platforms, one livestock producer mentioned that animals might not get wind and, therefore, would

[26] Some of the studies focusing on microclimatic changes under AgroPV systems analyze the variables such as temperature of soil, air, plant and panel, soil moisture, evaporation, wind speed, wind direction, water requirement etc (Marrou et al 2013, Adeh et al, 2018, Amaducci et al 2018, Barron-Gafford et al 2019, Weselek et al 2021a. In general, synergistic findings were achieved in the environmental (especially irrigation efficiency) and agronomic area (crop productivity) especially in dry and hot weather conditions. However, it is important to conduct research on microclimatic effects for large-scale AgroPV systems (Adeh et al, 2018).

not prefer to stay under the AgroPV panels during very hot summer days (#16). As a result of microclimatic effects, Weselek et al (2021) determined that the plant height and leaf size were relatively higher under AgroPV. These issues have also been raised by one of the farmers (#8) and he wanted to know whether these possible impacts were detrimental to agricultural production or not.

ii) Restrictions on switching or rotating crops

As noted above by several of our interviewees, consolidation of panels over arable land with rotating crops would be difficult as certain crop types are suitable for the area under panels. The crop choice is essential in benefiting from the synergistic effects of PV modules. This would also imply that panels would restrict the diversification of crops across years (#12). For instance, crops such as corn are traditionally planted in turn with other crops (#12).

All these concerns indicate that AgroPV investments would be more suitable when the land is covered by perennial crops (fruit trees etc.) that are expected to remain on the ground for an extended period of time (#12). With other types of crops, either farmers should be willing to plant one of several types of crops for extended periods (which is more difficult with a lack of state planning or market stability), or there should be a case-specific design flexible enough to be adapted to local conditions and allow users to switch crop-rotation and adjust to new market trends in agriculture.

iii) Operational problems

Several interviews expressed concerns about potential operational problems in agricultural production due to PV panel installations. Most agricultural practices rely on the application of some machinery. PV modules and the holding system might create challenges for agricultural machinery operation under or between the modules. For instance, the interviewees said that equipment such as tractors, combine harvesters, and pruning machines may be difficult to operate around or under PV panels (#12). If such machinery had to be replaced with labor (i.e., hiring labor for pruning citrus trees), it would increase the costs.

The agricultural activity below or between the modules might also create challenges for the PV systems. For instance, an interviewee (#12) raised the possibility that the chemicals with acidic components used as pesticides might harm the iron construction and panels, thus diminishing their expected life. The maintenance of the panels could be more difficult, i.e., module cleaning due to elevation height or troubles with replacing damaged parts while crops are in vegetation. The humidity might also risk (or reduce the lifetime of) the PV modules (#8).

Theft might be another problem. Several interviewees were concerned about the risk of stolen panels as they were aware of theft becoming more of a problem in the rural areas (this might be due to increasing rural poverty and/or deterioration of administrative structures in villages due to current social and political processes).[27] An interviewee (#9) indicated that many farmers opted for mobile solar panels due to the risks of panels being stolen. The same risk would also exist for AgroPV panels, although it would be more practically more difficult because of the elevation of

[27] Within the Metropolitan Municipality Law No. 6360 in 2012, the local administrative legal status of the villages was abolished and into neighborhood units.

the panels. The construction of panels should be accompanied by 'security' infrastructure such as fencing or cameras.

iv) Capital Demand and Operational Costs

The costs of the PV modules and the holding system of PV modules (in particular, metal poles upon which modules were constructed) were a concern for most of our interviewees. Some of the interviewees pointed to the implications of design for costs. For instance, interviewee 2 pointed out that the height of the panels will be critical, as metal is very expensive, and metal poles would probably constitute a high percentage of the total costs.[28] Also, several interviewees (#9, #8) mentioned since wind loads on the structure enormously increase with a higher vertical clearance; these systems will also require a more solid foundation and material input, thus increasing costs significantly. Interviewee 8 argued that because of the high costs of elevated systems, a farmer might prefer to build conventional solar farms on marginal agricultural land instead of productive land. Interviewee 9 stated that meteorological information on the area might be essential to evaluate whether there may be any harm to panels from extreme weather events such as storms. The fact that the holding system and PV modules will probably be exported was also a concern, as the exchange rate has risen significantly in the last three years (#1).

Certain agricultural activities like horticulture tend to employ smaller machinery, significantly reducing the cost of mounting structures. Nevertheless, if machinery has to be used in horticulture PV systems, a specific vertical clearance and large pole distances will still be required. In any case, the system costs will depend on elevation, crop type, and machinery use. The dwarf trees, for instance, would imply lower installation costs than standard trees (#12).

While most interviewees were more optimistic about using electricity generated by AgroPV systems for their own use, they were more hesitant about potential gains from generating electricity for the grid. Part of the reason for this was related to the costs involved in infrastructure construction required for grid connection and integration.

v) Grid problems

In Turkey, grid connection and integration expenses are undertaken by solar energy investors. In remote regions, the costs may be too high. For instance, one of the interviewees (#9), located in a relatively remote area in Southeast Anatolia, mentioned that he has significant problems even in acquiring electricity from the grid for irrigating his farm, *"the infrastructure is old, and breakdown is frequent."* When there was a breakdown, he had to replace the electricity poles. These difficulties, the interviewee states, would also be a problem for many farmers if they want to supply the electricity generated in AgroPV systems to the grid. Therefore, our interviewee suggested that these systems might be more suitable for places with better infrastructure.

Some of the interviewees had been concerned about the probable impact of intermittent solar electricity production on the grid. They mentioned that the grid near the agricultural land is very old, and they had some concerns about selling the excess electricity to the grid and if they would experience voltage and power fluctuations. In PV energy generation in Turkiye, grid problems such as voltage failures and distortions are common and require systemic efforts to improve power

[28] For arable farming, the benchmark for vertical clearance is usually given by full harvesters with a height of up to 5 meters Pulkit (2021).

quality (Arıcı and Iskender 2020). We see that the grid and transformer issues are also essential for using solar energy in Industrial Zones in Turkiye (ODTU-GUNAM, 2020).

vi) Institutional Setting

Many of our interviewees raised legal and bureaucratic problems that may arise in acquiring AgroPV permits (#9, #1). This concern might not be relevant once the actual AgroPV installations take place. We may expect legislative changes to allow AgroPV investments on agricultural land as ongoing research and development projects prove the feasibility and desirability of AgroPV systems.[29] Yet, the observations about current practices reflect broader problems in the design and implementation of laws concerning land use changes that may be very important for adopting and implementing dual-use systems such as AgroPV. As summarized in the country context part, legislative and bureaucratic processes for establishing solar panels on arable land are highly burdensome.

Some interviewees also mentioned that the procedures required to acquire permission were too complicated and lengthy, even for the most educated and well-off farmers. For instance, interviewee #9 stated that it would be easier to have a Ph.D. rather than acquire a permit for setting up panels for generating the electricity needed for well pumps. Confirming feasibility involves "an enormous red tape" and takes 8 to 9 months. According to the interviewee, the bureaucrats who prepared these directives concerning rules were either unaware of the difficulties on the ground or were wary of farmers' conversion of agricultural land to solar farms. Another interviewee stated that the processes through which permits were granted were not transparent and hinted at possible cases of discrimination in return for bribes or political connections (#15).

Indeed, in traditional renewable energy investments, a lax policy towards granting these permits carries the risk of farmers or potential farmers substituting away from agricultural land use for energy investments, given high feed-in tariffs in solar energy. As a study on the adoption potential of AgroPV in Germany established, high policy-support is needed to make AgroPV systems competitive with ground-mounted photovoltaics. In that case, “adequate policy designs are needed to safeguard AV’s land-efficiency advantage, as most farmers would be incentivized to abandon farming beneath the AV system” (Feuerbacher et. al. 2022). Yet, if there are strong synergies in arid or semi-arid zones, the price premium of AgroPV systems may be much lower. In any case, minimizing the absolute decline in agricultural contribution margins and ruling out the risk of abandoning land cultivation beneath the AV systems should be taken into consideration in policy design.

As we summarized in part above, synergistic outcomes are highly likely in Turkiye, depending on the crop type and local topographic and climatic conditions. Certainly, experimental research will be needed on agronomic performance in various crops and settings to explore these synergies and how they affect economic benefits.[30] Yet, the bureaucracy seems to have already embraced a negative attitude against dual-use investments potentially conducive to agricultural production. In fact, our correspondence with the officials at the Ministry of Agriculture revealed that the Ministry

[29] Currently, GÜNAM is collaborating with the Turkish Agricultural Ministry to develop ‘living lab’ projects where AgroPV systems will be utilized.

[30] Using an analytical framework such as the one introduced by Feuerbacher et. al. (2021) may be highly useful in assessing economic benefits and adoption of dual land use systems.

stepped back from authorizing solar panels over greenhouses because of 'panels' negative impact on crop yields.[31] This seems to be a very 'cautious' position given that most studies on AgroPV systems on greenhouse rooftops are more favorable than other (ground-mounted) AgroPV systems due to the high need for energy in greenhouses.[32] The Ministry also issued a separate 'negative opinion' on AgroPV systems.[33]

The reasons behind this strong reluctance to enable merging energy investments with agricultural production probably stem from various factors. But one issue that came up in various interviews suggested that the complex procedures might have reflected the bureaucracy's way of dealing with potential abuses (#12, #1). For instance, an official at the Provincial Directorate of Agriculture mentioned that a farmer might receive a permit to build PV panels on the roof of a stable or greenhouse claiming to grow livestock or produce crops. According to the official, the farmer is primarily interested in generating income from selling electricity to the grid but uses agriculture as a cover. This type of abuse and 'pseudo-agriculture' may be challenging to detect or penalize with the current administrative infrastructure.

The concern about reduction in agricultural production as a result of increasing solar energy investments on arable land probably informs netting policy as well. In order not to incentivize solar energy production vis-à-vis agricultural production, the legislation does not enable a system of annual netting. But, for farmers with very low electrical energy requirement during most of the year, the monthly netting system implies unpaid electricity generation (#12). Enabling annual netting will increase farmers' income and recover their setup costs in a shorter period.

Apart from the reserved attitude of the bureaucracy in solar energy investments on arable land, uncertainties surrounding agricultural policy undermine farmers' ability to engage in long-term investments. Our interviewees expressed this idea in various forms as they talked about significant problems in agriculture. There is little planning guided by research and data. The state should work with universities and carry out research and development activities (#13, #11) and monitor every farm's activity (#2). More importantly, the input subsidies are outdated due to inflation (#3); the support mechanisms are meager and incompatible with producers' incentives (#10, #11, #16), which undermines predictability in the agricultural system. The changes in crop patterns, in accordance with changes in output and input prices, are common (almost all the farmers we interviewed have changed their crop patterns in the last decade). This weak institutional setting creates powerful incentives for farmers to focus on the short term. Among the symptoms of this 'short-term focus' is frequent crop changes to cover costs and the neglect of long-term sustainability, which has implications for the willingness and ability of farmers to adopt AgroPV systems.

vi) Environmental Problems

[31] Agricultural Solar Power Instruction Implementation Guide (July 1, 2022); Information Note on Greenhouse Solar Power Applications (April 8, 2022).
[32] Ezzaeri et al 2018, 2020; Cossu et al 2014.
[33] Agrivoltaic Solar Energy System Information Note (May 30, 2022).

A concern about AgroPV systems is the use of concrete on arable land.[34] But, only one of our interviewees (#9) mentioned this as a potential problem and stated that recycling solutions might easily be found. Overall, there was little concern about 'potential' effect of AgroPV systems on the environment (apart from those on productivity through the impact of panels on soil quality). The absence of comments on 'landscape quality' is also striking.

Concluding Remarks

In the semi-arid Mediterranean context, solar radiation is a vital mitigating factor for the conflict between agricultural yield and energy output. In fact, the synergistic outcomes are highly probable as AgroPV may also serve as a shield against extreme weather events, contribute to soil water retention, and create favorable microclimatic conditions in arid and semi-arid conditions, thus contributing to yield stability. In the Turkish context, in addition to mitigating the climate risks, AgroPV may be a solution to the rising input costs, given high import dependency and exchange rate volatility. By enabling farming communities' own-energy production, diversifying agri-food activities that allow high value-added farming, and ensuring a double income stream (crop-food and energy), AgroPV systems may contribute to farmers' livelihood. Thus, it can also reverse the youth's escape from agriculture. As such, AgroPV may be an integrated solution to small and medium farmers' problems in the Turkish context and thus contribute to food security. Our interviews reveal that the pioneer farmers recognize and highly value this synergistic potential although they have had no experience with AgroPV systems. In particular, they are perceptive about how AgroPV systems might help alleviate local problems, including those exacerbated by climate change, beyond an abstract (economic or financial) opportunity dimension.

Despite the strong motivational drive for AgroPV given the challenges in Turkish agriculture, however, the weak institutional setting may channel farmers away from its adoption.[35] Socio-economic conditions, particularly frequent price fluctuations and the erratic support policy, deter farmers from undertaking investments with high setup costs and committing to permanent or semi-permanent arrangements. Therefore, designing AgroPV systems that are flexible enough to be adapted to local conditions and allow users to switch crops and adapt to new market would be fundamental. As an alternative, the government should introduce complementary policies that stabilize crop patterns in line with food security and environmental concerns. A feed-in tariff scheme that would ensure farmers' income stability given crop price fluctuations may also be important for long-term commitment. But, a favorable tariff scheme might also incentivize farmers to abandon farming beneath the AgroPV system. A reduction in agricultural production already seems to be a serious concern for the bureaucracy despite potential synergies due to the conditions in Turkish agriculture. Probably because of its low monitoring capacity, the agricultural bureaucracy is wary of abuses (i.e., 'pseudoagriculture') and became reluctant to grant permits for energy investments in agriculture. This problem, in return, explains farmers' negative experiences such as red tape, contributing to their doubts about sustained government support. For AgroPV systems to be introduced and expanded in a developing country setting, we not only need more

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[34] Regarding groundwork techniques, the literature recommends to avoid the use of concrete on arable land since concrete reduces fertility and soil permeability with its adverse effects on crop growth. The dismantling of the mounting structure after the lifetime of the system may be a costly and complex procedure in which the use of heavy machinery potentially causes soil compaction and hence soil degradation. Thus, the literature emphasized that systems that are drilled or rammed should be favoured when installing a Horticulture PV system.

[35] For innovation in agricultural sector, there are similar findings. Tunalioglu et al. (2016) discuss the impact of weak institutional setting on innovation in agricultural SMEs.

research and extension demonstrating the potential benefits of the AgroPV systems but also an understanding of the institutional setting within which farmers and bureaucrats operate and interact.

At the micro-level, providing farmers with information regarding the following factors seems crucial for adopting AgroPV technologies: Technical and agronomic details on the compatibility of each crop type with AgroPV technologies in terms of both productivity gains and operational costs; financial information on setup costs and cost savings due to own-energy use. In case of grid connection, expected income from electricity generation for sale would also be important. But, this would depend on regulations concerning permits/licenses as well as possible tariff policy; which is difficult to foresee. Given the rising vulnerability to drought and extreme weather events, the potential benefits of AgroPV are expected to rise. Therefore, information on climate change and long-term projections on how climate change will affect local production may also be crucial for farmers' decision-making. At the macro-level, exploring how legislative framework and institutional culture interact with policy design to shape incentives and reinforce mutual distrust would be important. Identifying policies that enable renewable energy investments to be in line with 'agricultural needs and purposes' will be key in enabling widespread adoption of AgroPV systems.

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