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Research Article

Farmers' Willingness to Contribute to the Realization of an Electricity Self-Sufficient Village Using Agrivoltaics. Results of a Survey

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ABSTRACT

With the Green Deal, the energy transition in the EU has gained momentum. Almost half of electricity consumption is now met by renewable energies. However, increasingly decentralized power generation is placing different strains on the centrally structured power grid, reaching its capacity limits. It is there for equestionable whether this will be sustainable. The ideal power supply would be located where the electricity is consumed. In this context, a decentralized energy system is being modeled to create an electricity self-sufficient village using agrivoltaics. Energy sharing among citizens, commercials, municipalities, and farmers creates a self-managed energy community. Farmers play a key role in this dual land use. This paper examines the central research question of farmers' willingness to contribute to an electricity self-sufficient village using agrivoltaics. The investigation draws on a survey of 215 German farmers. The survey results show a trend toward local, self-sufficient electricity generation supported by local actors. It is interesting to examine the extent to which farmers in the village are motivated and understand their role. Several policy implications can be formulated to support the realization of an electricity self-sufficient village using agrivoltaics. In the first step, electricity self-sufficiency is aimed in the sunny months from March to October, until cross-seasonal storage media are available and ready for series production.

INTRODUCTION

With the European Green Deal, the EU aims to become the first climate-neutral continent by 2050 [1]. In 2024, the share of renewable energy account for 47.4% (2019: 34%) of electricity consumption in the EU [2]. Solar was the fastest growing EU power source by 54 terrawatt hour (+22%) in comparison to 2023 [2]. This increase was due to a record amount of new capacity additions, and despite slightly lower solar irradiance compared to 2023. Solar provided 11% (304 terrawatt hour) of EU electricity consumption in 2024 [2].

The energy transition poses challenges for the current centrally positioned electricity system. Both the electricity distribution grid and the transmission grid are reaching their capacity limits in many places [3]. As the location of generation changes and renewable energies are characterized by more frequent peak load profiles [4]. The total volume of measures for grid congestion management, red is patch measures with market and grid reserve power plants as well as counter trading, was around 34,294 gigawatt hour in 2023 and has increased by 4.6% compared to the previous year (2022:32,772 giga watt hour) [5]. That is an 8.1- fold increase in this decade (2014:4,249gigawatt hour). The preliminary total costs amounted to around 3.1 billion Euro and, despite increased quantities, are around 24% (around 1.1 billion Euro) lower than in the previous year [5].

These two opposing trends are leading to tensions. On the one hand, significant expansion is needed to cover the other half of electricity consumption with renewable energies [6]. On the other hand, excessive expansion will lead to overloading of the electricity grid [4]. Possible solutions discussed include lengthy grid expansion [4], smart grids [7,8], or local battery storage [9,10]. The ideal electricity supply would consist of producing electricity where it is consumed. This would have the advantage that the electricity would not have to be transported over long distances and thus there would be no loss of efficiency during transport [4]. In this context, a model of an electricity self- sufficient village using agrivoltaics is being developed. By sharing energy, farmers citizens, commercials, and municipalities can generate local electricity together in an energy community and consume it at the same place.

This paper examines a model of a decentralized energy system for the realization of an electricity self-sufficient village using agrivoltaics. The farmer will be a key player in such an electricity supply arrangement. According to the authors' research, this paper is the first to examine farmers' willingness to contribute to such an electricity supply arrangement. This gap addresses the potential of the central research question, of what is farmers' willingness to contribute to an electricity self-sufficient village using agrivoltaics.

This survey focusses on southern Germany, as more hours of sunshine provide the productive basis for agrivoltaics. Representative data with observations of 215 farmers were collected. Of those, 175 farmers (81.40%) are already invested in photovoltaics, for example in rooftop system, so the opinion of the most farmers is based on initial experience with photovoltaics.

After the introduction in section one, section two provides a short literature review on agrivoltaics and model of the electricity self-sufficient village using agrivoltaics. Section three describes the methodology of data analysis. In section four, the empirical results are presented. Section five discusses the key findings in context of the research question and draws possible implications for the renewable energy market.

LITERATURE REVIEW

Farmer is enabler for agrivoltaics. A comprehensive review of two decades of research on agrivoltaics revealing an 18.21% annual growth in research on agrivoltaics [11]. Agrivoltaics combines energy production and agricultural crops in one location, addressing the growing demand for sustainable and cost-effective energy sources as base for dual land use [12]. Included, 85% of an agricultural land must remain available for agricultural use to receive the EUGAP premium [13]. Based on DIN Spec 91492 there are different categories and types considered and defines reduces of the agriculturally usable land are by a maximum of 15% [14]. Based on literature data, no crop type has an exactly proportional decrease in yield due to an increased level of shading [15]. Results of an analysis on the land use potential of agrivoltaics in Germany show that agrivoltaics over permanent, moderate shade-tolerant, and full shade tolerant crops can achieve 88% of Germany's photovoltaics energy target by 2030 [16]. Agrivoltaics are growing in popularity [17,18]. However, profitability is an important factor for the farmer, as the levelized cost of electricity is 38% [12] or, in a recent study 23.81% [19] higher compared to ground-mounted photo voltaics systems, depending on the category of agrivoltaics system chosen. Therefore, substantial policy support is required to make agrivoltaics competitive with ground-mounted photovoltaics [20]. Despite the less cost-effectiveness a discrete choice experiment of the German population(N=1,893) shows, that agrivoltaics are more acceptable than ground-mounted photovoltaics [21].

In the energy sector, self-sufficiency means independence from large electricity suppliers. Independence can range from partial to complete [22]. If electricity is generated from one's own sources such as agrivoltaics, the degree of local self-sufficiency increases. McKenney et al. [23] consider different degrees of self-sufficiency:

- Tendency towards energy self-sufficiency, e.g. tendencies towards a decentralized energy supply, but energy self-sufficiency is not formulated as an explicit target,
- Balance energy self-sufficiency, e.g. the region is self-sufficient throughout the year with the supra-regional grid infrastructure being used to balance discrepancies between supply and demand.
- Complete energy self-sufficiency, e.g. the village is energetically separated from its surroundings and constantly and completely covers its own energy demand itself.

Energy communities allow groups of individuals or consumers to establish legal entities that produce, consume, store, share and sell renewable energy [24]. Various scenarios and combinations of producers, consumers and prosumers are thinkable [25]. The target is to identify optimal configurations that maximize various key performance indicators, with total self-consumption and self-sufficiency being among the most important. The three most important indicators are 1) shared energy, 2) self- consumption, and 3) self-sufficiency [26]. The economic viability of energy communities depends on the inter play of three key energy components: 1) direct-self consumption, 2) shared energy and 3) energy fed in the grid [26]. This can serve as a base and frame for scaling an electricity self-sufficient village using agrivoltaics.

With this understanding of self-sufficiency is intended to analyze the pros and cons. As pros can be summarized: The consumption of locally generated electricity can make a significant contribution to security of supply and promote more efficient use of agrivoltaics [27]. In addition, local generation and consumption can ensure affordable electricity prices for consumers [28] and promote independence from large energy suppliers [29,30]. By generating and storing electricity capacities locally, as well as incentivizing consumers based on generation times, supply and load curves can be smoothed and the residual load, e.g. the load minus the current feed-in, can be reduced. As the system scales up, energy production and consumption can be dynamically balanced across a larger number of households. This leads to cost-saving effects in the energy community while promoting sustainability and efficiency, leading to better use of agrivoltaics [8]. In addition to the economic aspects, ecological and social aspects are addressed and promoted [23]. However, there are cons: Peter concludes in his analysis that complete real electricity self-sufficiency will only be possible in rural areas and not in cities, and only if electricity storage systems are considered [31,32]. McKenna et al. [23] question the economic viability of real self-sufficiency, as a second grid infrastructure would have to be built, which would be at the expense of overall welfare.

The envisaged model of an electricity self-sufficient village using agrivoltaics can be classified in terms of the levels of self-sufficiency between level 3 total self-sufficiency and level 2 balance sheet self-sufficiency. The model primarily aims for total self- sufficiency, as it attempts to generate its own electricity consumption. This is limited on the one hand using the local distribution grid, as it is not proportionate to build up additional grid infrastructure for welfare reasons. On the other hand, the limitation is due to the hours of sunshine in the winter months, as agrivoltaics cannot generate enough electricity. In addition, the energy community tries to sell excess capacity in the summer and feed it into the public grid. For this purpose, a connection to the public power grid is desirable. This business model not only shares electricity but also responsibility in an energy community [33]. It will have the following key points, which distinguish it from a purely mathematical calculation example and will serve as reference:

- Agrivoltaics as a basic technology for duall and use
- Smart meter technology as a basis for different tariffs (sunshine vs. darkness)
- Battery storage as a possibility for greater self-sufficiency
- Local investment in distribution grid as a contribution to energy security
- Energy sharing as a basis for organized shared electricity use
- Energy community as an instrument for public participation
- Flexible dimensioning and adaptation to the size of the village
- Creating local employment by administration of the energy sharing
- Higher profitability of this model in comparison to a regular agrivoltaics

METHODOLOGY

The data were collected as part of are presentative survey among German farmers. For this purpose, websites of agricultural companies were searched online, and their email addresses were obtained. A total of 2,903 email addresses were contacted with a standardized cover letter and a link to the online survey. The online questionnaire was answered by 290 respondents between January 10 and February 28, 2025. This corresponds to a response rate of 10.00%. Of these, 215 completed the questionnaire to the end, which corresponds to a completion rate of 74.14%.

This population (N=215) is compared with all German agricultural companies (N=255,010) in 2023 [34] and reflects the German farms in terms of gender, age/vintage group and agricultural land. However, the focus on southern Germany, Bayern (29.77%), Baden-Württemberg (28.37%) and Rheinland-Pfalz (20.00%), shows explainable sector differences: the livestock population is lower, and the fruit, wine-growing and mixed farms are higher than in the German total. The higher level of commitment to renewable energies in the southern German population is to be expected: investments in photovoltaics are significantly higher. Interesting in possibly in explicable due to the geographical focus is the level of education: while no one in the population is without a vocational qualification, the total German data show a proportion of 38.93% and a significantly low university degree of 8.86%. There as on for this could be that few or no part-time farmers are included in the population, because the farms contacted operate a website, which in turn is primarily done by full-time professional farmers.

An indication of an intact population is that just a few farmers state that they are phasing out their businesses (3.26%). Only a minority would like to focus on their core business farming (22.79%). Most farmers would like to diversify their operations and are open to new business areas (73.95%). This high entrepreneurship rate is impressive.

RESULTS

The empirical data of the population (N=215) are presented using descriptive statistics. The model of realizing an electricity self-sufficient village using agrivoltaics is viewed positively by most of the respondents (Figure 1).

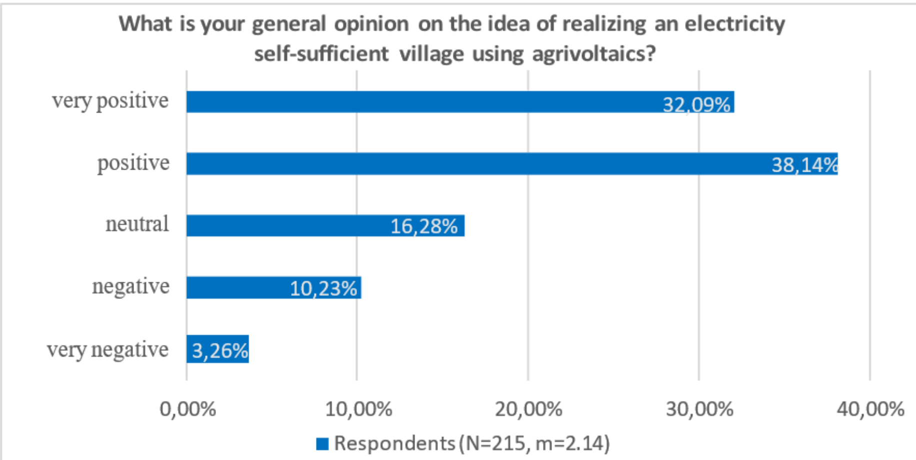

Figure 1: Electricity self-sufficient village using agrivoltaics.

Concerning the research question of what farmers' willing to contribute, it is important to know what business profit is required to contribute to an electricity self- sufficient village using agrivoltaics. The following figure shows that most farmers aim to achieve a business profit from 1,000 to <10,000 Euro per year (37.67%), excluding their own labor hours and land lease, which are already compensated at market rate (Figure 2).

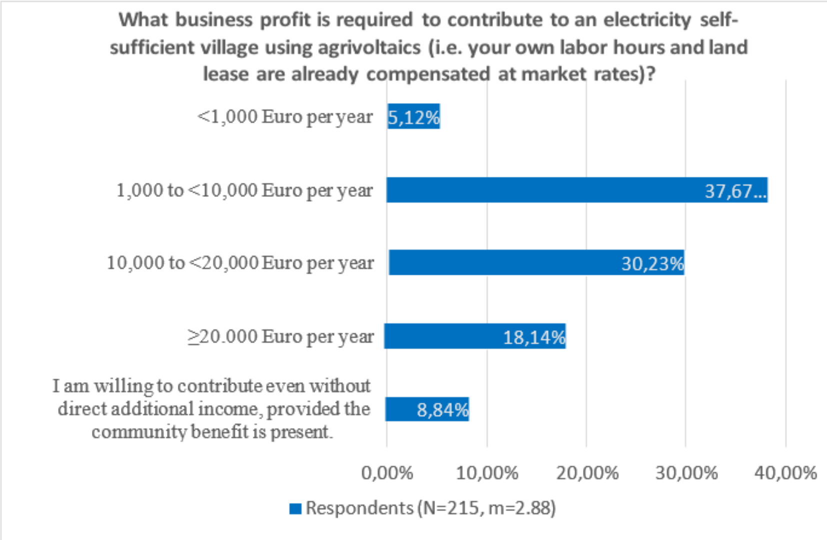

Figure 2: Business Profit.

Furthermore, the results also show that the model has far-reaching implications for the integration of agrivoltaics and electricity self-sufficient villages onto agriculture (Figure 3).

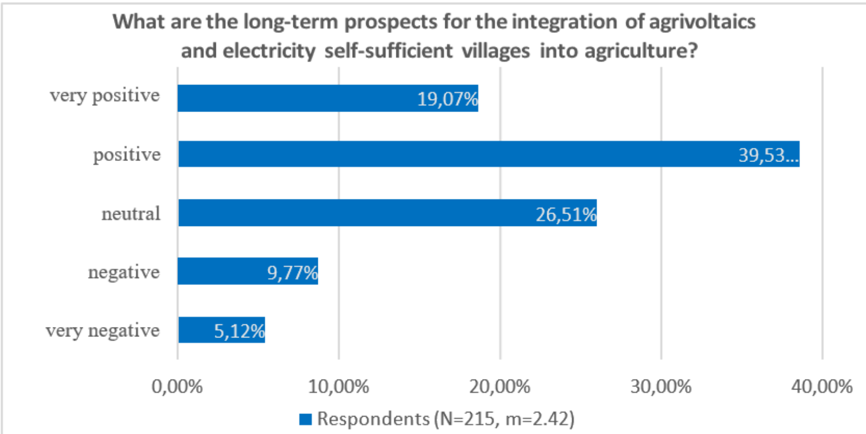

Figure 3: Integration of agrivoltaics and self-sufficient villages into agriculture.

DISCUSSION AND CONCLUSION

Solar energy is considered crucial to achieving the goals of the EU Green Deal [35]. However, its rapid expansion shows that centrally designed power grids are reaching their capacity limits. One possible solution to this dilemma is to produce electricity where it is consumed. In this context, the model developed for the realization of an electricity- self-sufficient village using agrivoltaics contributes to this. In an energy community, farmers, commercials, citizens, and municipalities can share energy. Farmers play a key role in this by enabling dual land use.

The survey results show that most of responding farmers positively evaluate the model of an electricity self-sufficient village using agrivoltaics. This is consistent with an analysis in Kosovo, which emphasizes that farmers strive for their own electricity self- sufficiency and, moreover, play a significant role in local economic development [18]. A broader participation of farmers is underscored by an analysis in France, where agrivoltaics emerge through local collective self-sufficiency loops [36].

The results demonstrate farmers' willingness to contribute to such an electricity supply arrangement. The farmers are not presumptuous, as they do not demand the maximum business profit of 20,000 Euro per year or more offered in the survey. Farmers recognize the additional effort required to manage an energy community and market the electricity to its members. Most farmers are willing to participate in an electricity self- sufficient village using agrivoltaics for a business profit of between1,000 Euro and <10,000 Euro per year. Furthermore, the survey results also underscore the importance for farmers of energy sharing in an energy community: An altruistic minority of 8.84% would participate in such an electricity self-sufficient village even without direct additional business profit, provided the community benefit is present. This is consistent with an analysis by Vezzoni, who emphasizes that profit alone will not be sufficient as a motive [37].

The long-term prospects of integrating agrivoltaics and an electricity self-sufficient village using agrivoltaics into agriculture are viewed positively by most farmers. Initially, this is understandable, as agrivoltaics is considered as a win-win solution for developing solar energy while simultaneously increasing agricultural productivity [12]. It also offers several other benefits, including decentralized electrification, improved crop yields, and thus higher farmers' incomes [12]. Furthermore, the necessary grid expansion is not possible at the speed is required to ensure energy security [4,38]. However, there are warnings at the interface between agriculture and solar development: In his paper, Vezzoni laments cost shifting due to the pollution of agricultural land or even the displacement of farmers [37].

In summary for further expansion, agrivoltaics can make a significant contribution to the other half of the EU energy transition. The examination of the central research question of what farmers' willingness is to contribute to an electricity self-sufficient village using agrivoltaics, show a trend toward energy sharing in an energy community. Farmers play a central role and are willing to actively contribute to the energy community in return for a moderate business profit. The results show that farmers view the integration of agrivoltaics and the model of the electricity self-sufficient village as a positive long-term solution to strive for the ideal electricity supply, production and consumption at the same place.

Several policy implications can be formulated to gain famers' willingness to contribute to an electricity self-sufficient village using agrivoltaics. First, all agrivoltaics categories should be legally considered according to DINSPEC agrivoltaics system, so that many farmers and crops can participate. Second, energy sharing should be supported in all countries in accordance with the requirements of the EU Directive 2018, so that energy communities can be formed. Third, energy communities should be given the chance to the use of the distribution grid, so that physical energy sharing is also possible. Fourth, the grid operators should be incentivized to maintain further the distribution grid sothat they are not in direct competition with energy communities.

The potential of the results must be put into perspective. Two limitations should be highlighted. First, the selection of farmers based on websites to obtain their email addresses implies a certain level of professionalization. Second, the focus was on southern Germany with higher solar radiation, implying a higher affinity for agrivoltaics.

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