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Acceptance for the second half of the energy transition through electricity self-sufficient village using agrivoltaics?

Martin* Bauknecht

[1] University Hohenheim, Institute of Agricultural Policy and Markets, 70599 Stuttgart, Germany

Abstract. With the Green Deal, the energy transition in the EU has gained momentum. Almost half of electricity consumption is now covered by renewable energies, in which solar energy plays a significant role. However, the massive expansion of photovoltaics is becoming increasingly noticeable and is being felt by every individual locally. Neither the current high electricity price level nor the changing landscape provides any motivation to further advance the energy transition. These two trends raise the question of how acceptance for the second half of the expansion can be maintained and achieved. In this context, a decentralized energy system is being modeled to create an electricity self-sufficient village using agrivoltaics. This has the advantage that the land can be used for dual purposes. The shared use of energy between 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 what contribution an electricity-self-sufficient village using agrivoltaics can make to social acceptance. This paper is based on a survey of 215 German farmers. This survey results show a trend that local social acceptance can be increased through civic engagement. Various policy implications can be formulated for the realization of an electricity self-sufficient village using agrivoltaics. The first step is to achieve electricity self-sufficiency during 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 22% (+54 TWh) 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 TWh) of EU electricity consumption in 2024 [2].

Electricity prices in the EU have fluctuated sharply in recent years due to the energy crisis. Due to the sharp rise in energy prices since 2022, almost all countries introduced measures to relieve the burden on end consumers, some of which will not be extended as the energy markets have stabilized [3]. In mid-2024, the average electricity price in the EU was 28.9 cents/kWh for private consumers (2014: 22.6 cents/kWh) [3]. This represents an increase of 27.9% within this decade. The differences in electricity prices are enormous. In 2024, the highest electricity price was in Germany at 39.5 cents/kWh (36.7% above the EU average), and the lowest electricity price was in Hungary at 10.9 cents/kWh (62.3% below the EU average) [4]. Price differences arise from various closely interrelated factors, such as geographical conditions, the share of renewable energy in the electricity supply, and dependence on energy imports [4]. Political conditions, such as government subsidies and taxes, also influence the final prices ultimately charged to consumers [4]. In high-price countries such as Germany, a crucial aspect is the comprehensive expansion of renewable energy as part of the energy transition, which requires significant investments in infrastructure and technology. These costs are partially passed on to consumers, contributing to the high consumer prices [4].

* Corresponding author: m.bauknecht@uni-hohenheim.de

The energy transition and the associated further expansion of renewable energies is in line with the Green Deal continue to require social acceptance among the population. In the future, even more energy will be generated, transmitted, and stored using systems exposed to the landscape [5]. The resulting landscape changes are controversially discussed, as they can lead to land-use conflicts and have a negative aesthetic impact on the landscape [6]. Surveys show that solar energy enjoys a high level of general acceptance among the population [7] and is preferred over other renewable technologies [8]. However, public acceptance dwindles, for example, as project size or intensity increases [8], [9] Acceptance of the technology is important, as public resistance can slow down or even prevent further expansion [5]. Regarding solar energy, an analysis by Zeddies et al. shows that agrivoltaics is more accepted than ground-mounted photovoltaics [10]. Furthermore, participants in this analysis are even willing to pay more for the electricity generated by an agrivoltaics than for that generated by a ground-mounted photovoltaics [10]. However, despite higher acceptance, the agrivoltaics is also considered to have a negative impact on the landscape [10]. Beside the technology in various analysis the population participation is seen as a key to further increasing local acceptance [11], [12].

These two opposing trends are creating tensions. On the one hand, significant expansion is necessary to cover the second half of electricity consumption with renewable energy [8]. On the other hand, excessive expansion reduces acceptance due to landscape impacts and rising electricity prices due to subsidies for renewable energies. Possible solutions to bridge these tensions could be the involvement of local citizens. The ideal electricity supply would be to generate electricity where it is consumed. The advantage would be that citizens can participate in energy production and thus both increase local acceptance of the energy transition and, as electricity producers, influence the price. 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 social acceptance of the farmers for the second half of the expansion can be maintained and achieved. This gap addresses the potential of the central research question, of what contribution to social acceptance can an electricity self-sufficient village make 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, acceptance 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, and the key findings are discussed in context of the research question. Section five concludes the key findings, possible implications, limitations and further research questions for the renewable energy market.

LITERATURE REVIEW

A comprehensive review of two decades of research on agrivoltaics revealing an 18.21% annual growth in research on agrivoltaics [13]. 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 [14]. Included, 85% of an agricultural land must remain available for agricultural use to receive the EU GAP premium [15]. 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% [16]. Based on literature data, no crop type has an exactly proportional decrease in yield due to an increased level of shading [17]. 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 [18]. Agrivoltaics are growing in popularity [19], [20]. However, profitability is an important factor for the farmer, as the levelized cost of electricity is 38% [14] or, in a recent study 23.81% [21] higher compared to ground-mounted photovoltaics systems, depending on the category of agrivoltaics system chosen. Therefore, substantial policy support is required to make agrivoltaics competitive with ground-mounted photovoltaics [22]. 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 [10]. In the energy sector, self-sufficiency means independence from large electricity suppliers. Independence can range from partial to complete [23]. If electricity is generated from one's own sources such as agrivoltaics, the degree of local self-sufficiency increases. McKenney et al. consider different degrees of self-sufficiency [24]: 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 [25]. Various scenarios and combinations of producers, consumers and prosumers are thinkable [26]. 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 [27]. The economic viability of energy communities depends on the interplay of three key energy components: 1) direct-self consumption, 2) shared energy and 3) energy fed in the grid [27]. 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 [28]. In addition, local generation and consumption can ensure affordable electricity prices for consumers [29] and promote independence from large energy suppliers [30], [31]. 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 [32]. In addition to the economic aspects, ecological and social aspects are addressed and promoted [24]. 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 [33], [34]. McKenna et al. 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 [24]. 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 [35]. 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 dual land 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 a representative 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 [36] 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 inexplicable 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%. The reason 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 and discussion

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 (70.23%). This can be described as a good foundation for embarking on the second half of the energy transition with such a model, because the social aspects of the energy transition gain importance as the transition are moving closer to the reality of people's live [37]. Ultimately, farmers are key to dual land use, and they can also play a central role in the energy community for energy sharing. Commitment for agrivoltaics in the neighborhood (less than 5 km) is given and measured at 65% in a Fraunhofer ISE study [38]. With 68% commitment, is the result similar in an annual acceptance survey of AEE carried out by the opinion research institute YouGov [39]. In summary, the more visible agrivoltaics are built on agricultural land, the more important is to achieve acceptance with the citizens [40].

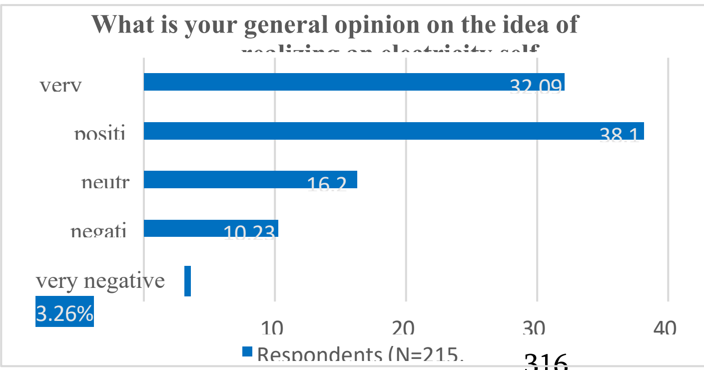

Fig. 1: Electricity self-sufficient village using agrivoltaics

Concerning the research question what acceptance of an electricity self-sufficient village using agrivoltaics. Most of the farmers see the contribution to social acceptance through realization of an electricity self-sufficient village using agrivoltaics positive to very positive (60.93%). Acceptance by local acting can be understand as ideal for controlling the realization an electricity self-sufficient village through agrivoltaics. Fischer et al. emphasize the locally anchored, regionally active, and democratically organized nature of an energy community. Through their participatory approach and their support for the energy transition, they can make a significant contribution to local acceptance [41]. Wirth sees a potential to increase acceptance by participation [38]. Research by Yildiz et al. underscore the importance of social capital and community participation in the success of energy sharing [42].

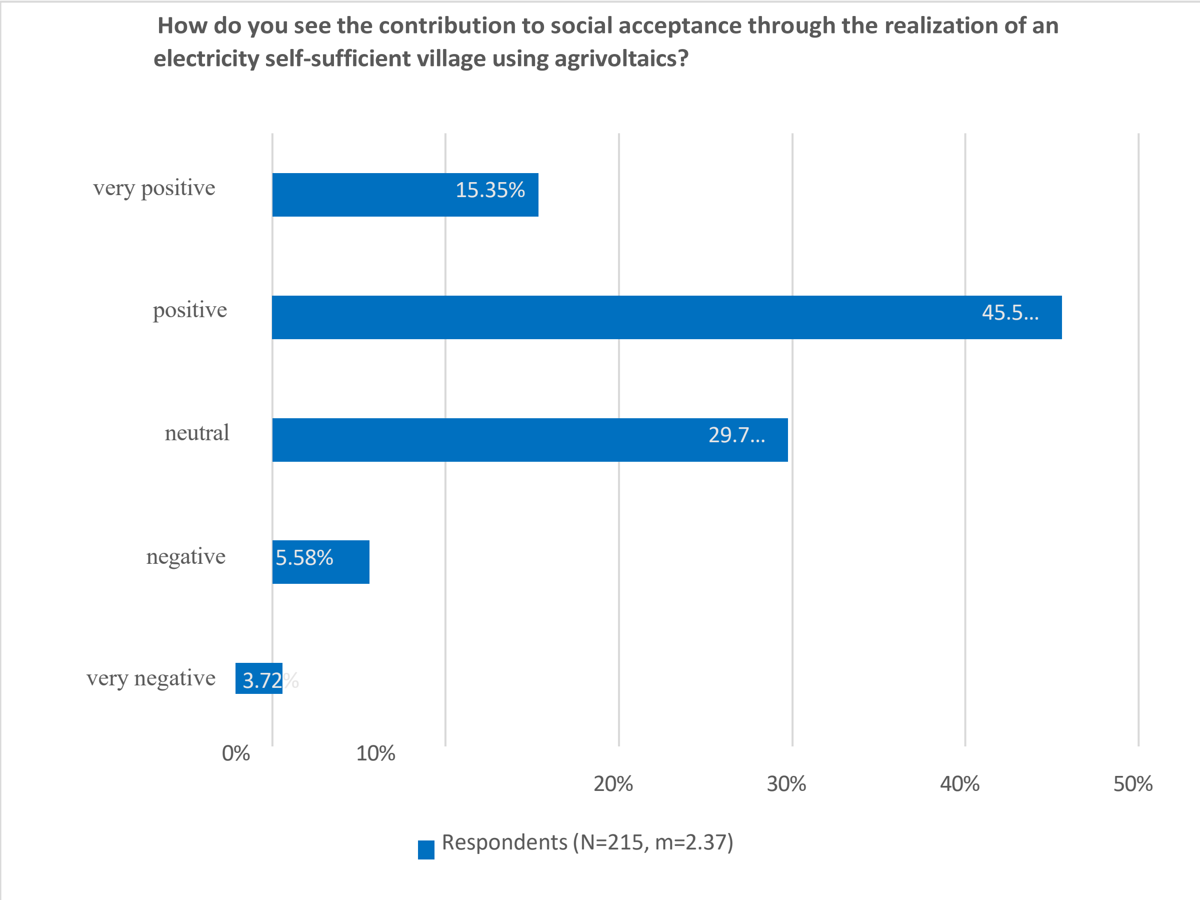

Fig. 2: Contribution to social acceptance

Furthermore, the results also show that farmers' acceptance get along with desired support for the farmers. The top three kind of support are first support with approval and planning (73.95%), second clear legal framework for energy sharing (58.14%) and third financial support for investments in an electricity self-sufficient village (58.14%). Farmers' wishes should be considered to ensure the success of realizing an electricity self- sufficient village using agrivoltaics. Furthermore, transparency can create greater acceptance. This approach is supported by Thomas & Aschermann-Witzel. They conceptualized a model with a more holistic understanding of stakeholders' different perceptions towards agrivoltaics. Their finding shows that diffusion process has a better chance of gaining local trust and social acceptance by providing a more holistic perspective on decisions. For example by insisting that farms become carbon neutral, or by involving key stakeholders such as local communities in decision-making and planning processes [42].

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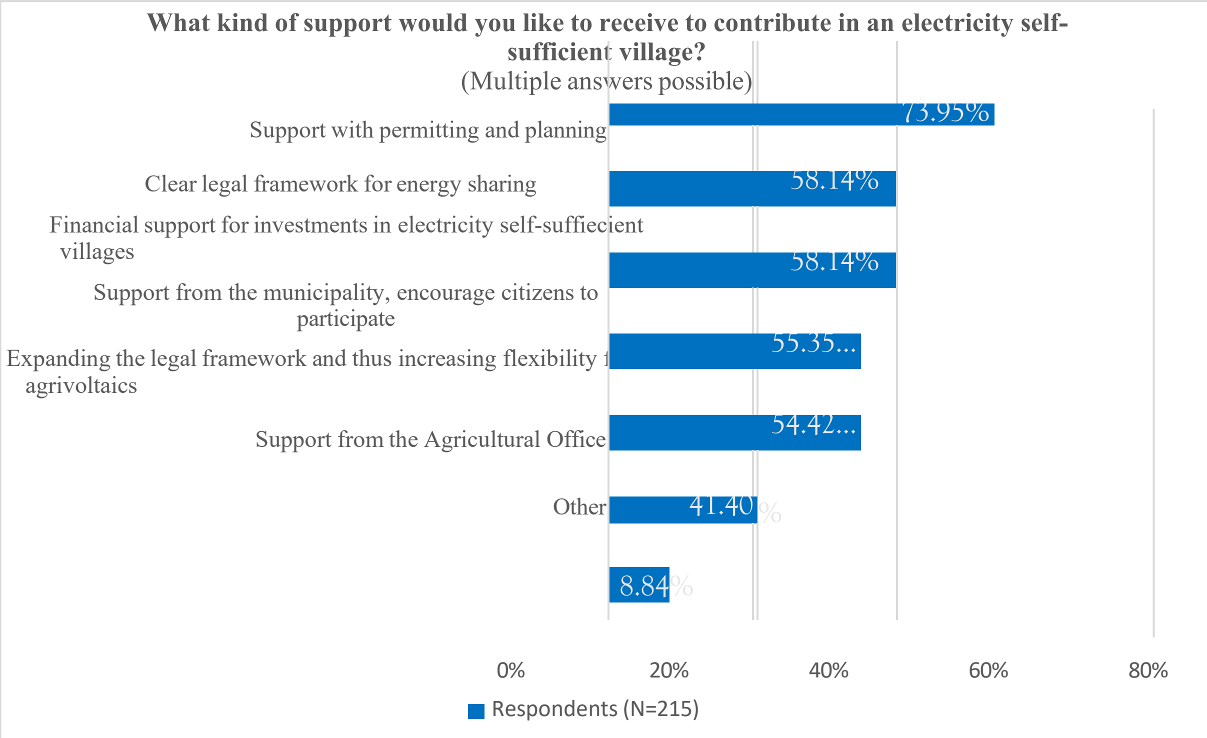

Fig. 3: Desired support for farmers

In summary, an electricity self-sufficient village using agrivoltaics holds great potential. Farmers demonstrated in the survey results that they want to contribute to dual land use within the context of their central role, even though they hope for support in its implementation. The decentralized energy system enables energy sharing within an energy community. In addition to farmers, commercials, citizens, and municipalities are invited to participate. Local engagement increases local acceptance and, from a global perspective, can make a significant contribution to the second half of the energy transition through a variety of energy communities.

CONCLUSION

The model of an electricity self-sufficient village with agrivoltaics could be a possible solution for the second half of the energy transition. The results of this farmer survey reveal significant insights into the acceptance of such a model. On the one hand, farmers want to contribute to an electricity self-sufficient village with agrivoltaics. On the other hand, there is desired support: first with permitting and planning, second a clear political framework for energy sharing, and third financial support for investments in an electricity self-sufficient village. In conclusion, policy implications can be derived. First, the approval and planning procedures for agrivoltaics should be clearly defined, consider as many agrivoltaics variants as possible, and be implemented in a non-bureaucratic manner. Second, a clear political framework for energy sharing should be established. Third, investment support, such as subsidy programs or special depreciation allowances, should be established to facilitate the realization of an electricity self-sufficient village using agrivoltaics.

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 higher affinity for agrivoltaics. Third, self-sufficiency can only be achieved during the summer months from March to October, until cross-season storage media are available and ready for series production. Fourth, the farmers' perspective is significant but should be supplemented by other perspectives.

Future research questions could address further perspectives on the puzzle. For example, a survey of citizens or municipalities could address the acceptance of such a model for the realization of an electricity-self-sufficient village using agrivoltaics.

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