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Agrivoltaics in Germany – Status Quo and Future Developments

Evaluation of the German Agrivoltaics Innovation Tender 2022 and Overview about the Agrivoltaics Development in Germany

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Abstract. Ground-mounted photovoltaic facilities in open spaces have been common in Germany for many years. However, according to the legislation, these are only supported by the government on poorer quality soils, former military training areas, or along traffic routes. Nevertheless, also on high quality soils it is not forbidden to install ground-mounted photovoltaic facilities. In recent years, Germany has started implementing agrivoltaics, which is an alternative land use concept that combines agriculture and renewable energy production. This opens the possibility to use land of higher soil quality for energy generation without necessarily creating land-use conflicts and being subsidized by the government. This study aims to provide a comprehensive overview of existing and planned agrivoltaic facilities in Germany analyzing them based on various parameters. The data for this study was collected through a community questionnaire and supplemented with data from state institutions.

The results indicate that as of March 2023, 21 agrivoltaic facilities with a total capacity of 81.67 MW_p have been installed. A strong increase of the installed capacity is expected in 2023 and 2024, reaching approximately 382.59 MW_P by the end of 2024. The market development of agrivoltaics is mainly driven by changes in the legal environment which present opportunities for further market ramp-up of agrivoltaics. The adoption of agrivoltaics shows a notable spatial diversity in Germany which appears to be influenced by the interaction between regulatory environments and agricultural structures.

Keywords: Photovoltaics, Agrivoltaics, Germany, Legislation

Introduction

Photovoltaics on roofs and ground-mounted PV are already well established in Germany's renewable energy sector. Next to wind power and biogas plants, photovoltaics is one of the major renewable energies in Germany. Photovoltaics are common on building roofs and in March 2022, already 2.2 million facilities with a total capacity of 58.400 MW_P were installed on German roofs [1]. Also ground-mounted photovoltaic facilities in Germany have been increasing in number and installed capacity (**Figure 1**). In 2020, 6,427 ground-mounted photovoltaics facilities were installed in Germany with a total capacity of 13,345.7 MW_P [2].

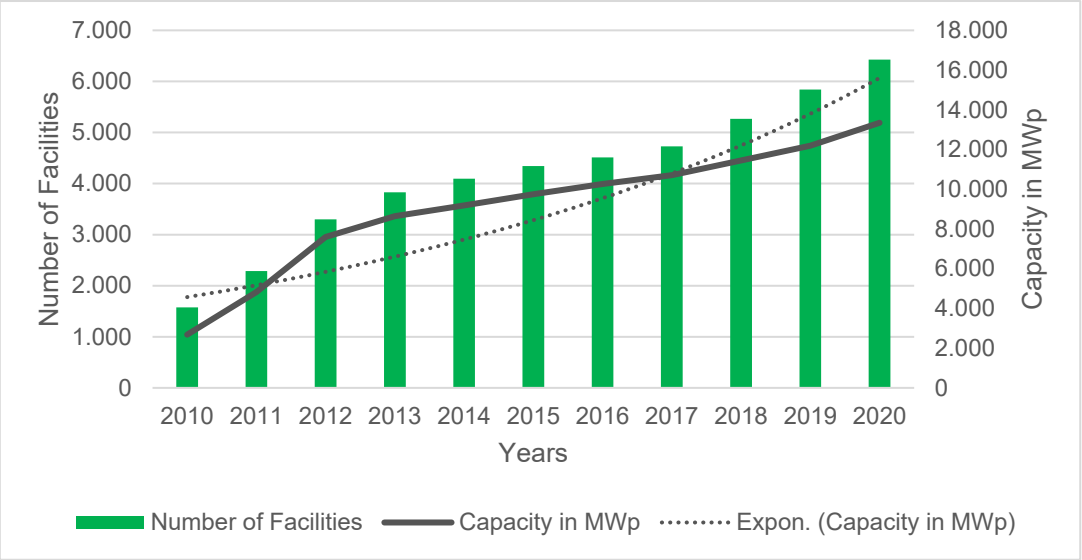

Figure 1. Ground-mounted photovoltaic facilities in Germany

According to the Federal Statistical Office of Germany, as of 2021, approximately 52 % of the total land area in Germany is used for agricultural purposes [3]. Extreme weather events are increasing in frequency and intensity worldwide – also in Germany. In addition to heavy rainfalls, droughts associated with climate change pose enormous risks for agricultural production. This is illustrated in the latest harvest report from the German Federal Ministry of Food and Agriculture, which shows a precipitation deficit in all months of 2022, except for February and April [4].

Agrivoltaics offers the opportunity to combine climate change adaptation and mitigation. Partial shading of crops and soil increases drought resilience, while solar energy generation reduces greenhouse gas emissions [5]. In Germany, agrivoltaics is an expanding new land use concept. This becomes evident by the number of already installed agrivoltaic facilities. The aim of this study is to present the status quo and development trends of agrivoltaics in Germany, including a comparison between the states and their varying conditions. To keep the actuality of this study it will be updated in regularly follow-up studies.

This study is relevant for companies in the renewable energy sector as well as farmers and land owners, who are planning photovoltaic facilities on their properties. Contributions of others in the literature are already existing for the definition of agrivoltaics [6] and studies of the potential in Germany [7, 8] as well as the development of the legal framework of agrivoltaics [9, 10]. Furthermore, there are different ongoing research projects that examine possible crops [11], social acceptance and other research questions.

Material

The data of this study is based on own research and the Federal Energy Grid Agency's (Bundesnetzagentur) market master data register (Marktstammdatenregister) [12]. The latter is publicly accessible and provides various data on the installed facilities. For example, the capacity of the facility and the location are recorded, as well as the commissioning date. In addition, a survey has been conducted within the SynAgri-PV research project (further information under "Funding"). The survey is distributed to the owners/operators of agrivoltaic facilities, after they are connected to the electricity grid. Design and style of the questions were developed in between the project consortium in several discussion rounds. This survey gathers additional data on existing agrivoltaic facilities, which could be relevant for improving facilities in the future. To ensure that the database is up to date and to continuously gain more detailed information from the growing experience, the survey is designed to be repeated at regular intervals. However, it is not fully evaluated yet but will be presented in upcoming publications.

Developments of agrivoltaics in Germany

To assess the progress of agrivoltaic facilities, it is necessary to examine the legal framework for renewable energies, specifically the legislation related to photovoltaics in Germany.

Legal Developments

Since 2000, the Renewable Energy Law (Erneuerbare Energien Gesetz – EEG) has set the legal framework for the energy transition in Germany [13]. In the 2021 novelty of the EEG, agrivoltaics entered the innovation rules as part of the so-called *special solar facilities* (together with floating photovoltaics and parking lot photovoltaics) [14]. In the federal innovation tender of April 2022, a grant volume of 150 MW_P was reserved for these *special solar facilities*. To participate in the tender, a bid had to be within 100 kW_P to 2 MW_P and a combined facility (agrivoltaic facility + e.g. battery storage). In addition to the Renewable Energy Law, industry stakeholders in Germany introduced a preliminary industry standard for the design of agrivoltaic facilities, called DIN SPEC 91434 in 2021 [15]. This technical rule differentiates between two main designs, both already installed in Germany. An interspace design, which is most suitable for grassland and animal husbandry, and the overhead design, which is mainly used in arable farming and horticulture.

It is noteworthy that only 22 MW_P out of the primary grant volume of 150 MW_P were utilized for *special solar facilities*. This underutilization may be attributed to the restrictive laws regarding the market ramp-up of agrivoltaics, apart from the Renewable Energy Law, such as the Building Law. Moreover, the maximum bid of 2 MW_P in the innovation tender may pose a barrier to constructing larger-scale and more economically profitable facilities. These possible reasons need to be explored in more detail, e.g., in the upcoming repetition rounds of the survey. However, there have been new legal developments at both federal and state levels to address these issues. For instance, the EU direct payments were reviewed to prevent the discontinuation of payments when constructing an agrivoltaic facility, which could jeopardize the operator's planning security. The recent regulation (November 2022) states that agrivoltaic facilities can still remain eligible for at least 85% of payments because the loss of land, according to DIN SPEC 91434, may not exceed 15% [16]. Although clarifying regulations have been adopted in other areas of law, further adjustments are still necessary.

Development of installed and planned agrivoltaic facilities

Agrivoltaics is still in a very early stage of development in Germany. **Figure 2** shows a timeline that illustrates the number of facilities (left axis) and the installed capacity (right axis) over time.

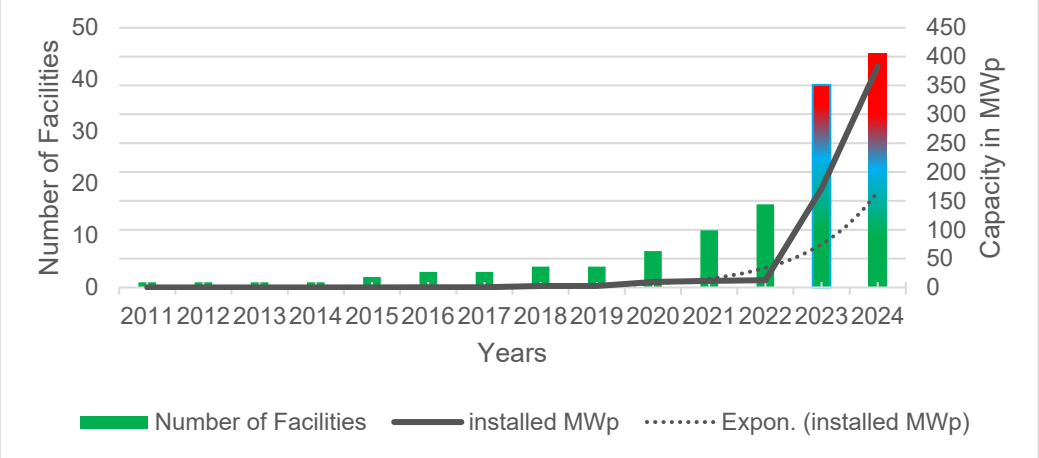

Figure 2. Development of number and installed capacity of agrivoltaic facilities in Germany

A closer look reveals that by 2020, seven agrivoltaic facilities were installed, with a total capacity of 9.42 MW_P. From 2020 onwards, an increasing development trend is recognizable. This could be due to expanding research activities and the implementation of research facilities as well as through the growing public interest. More in-depth research needs to be done for more accurate answers. By 2022, 16 facilities with a total capacity of 12.46 MW_P were installed. By the end of 2023, after the planned facilities (red and blue) will be installed, a significant jump in the number of facilities is expected. The data for 2024 is not complete, as it's assumed that new facilities are still being planned in 2023 for 2024.

So far, it is estimated that the number of agrivoltaic facilities will increase to at least 45 by 2024, while the installed capacity is assumed to rise from 12.46 MW_P to 380 MW_P.

Spatial distribution of agrivoltaics in Germany

The following map (**Figure 3**) shows the spatial distribution of all existing (green) and planned (blue and red) agrivoltaic facilities in Germany. By March 2023, 21 agrivoltaic facilities were installed in Germany.

Figure 3. Map of installed (green) and planned (blue, red) agrivoltaic facilities in Germany until March 2023, grey=not connected to the electricity grid; © OpenStreetMap

The planned facilities shown in blue depict the agrivoltaic facilities that are subsidized by the federal innovation tender from April 2022, while the red dots display other planned agrivoltaic facilities. Gray symbolizes agrivoltaic facilities that are not connected to the energy grid or where no further information is available.

Distribution of agrivoltaics by German states

A closer look at the expected number of facilities in 2024 reveals the following map with regard to the 16 states in Germany. Especially in southern Germany (by name Bavaria and Baden-Württemberg), the number of facilities is higher compared to the rest of Germany (**Figure 4**).

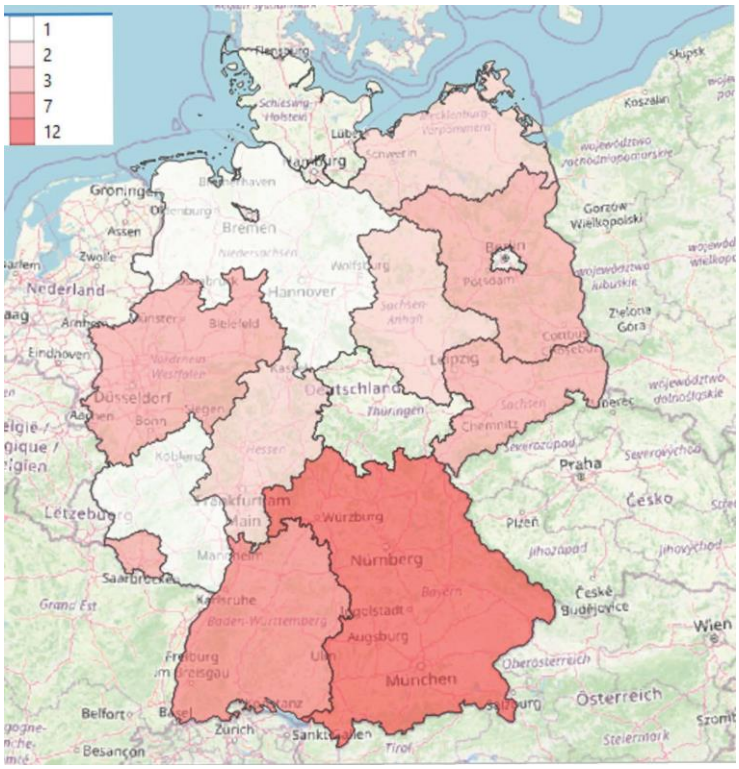

Figure 4. Number of installed and planned agrivoltaic facilities in the German states; © OpenStreetMap

Compared to this, the expected installed capacity presents a different picture. The anticipated installed capacity is not only particularly high in southern Germany, but it also in north-eastern Germany (Figure 5). This is primarily due to a few large facilities that are scheduled to be installed in north-eastern Germany by 2024.

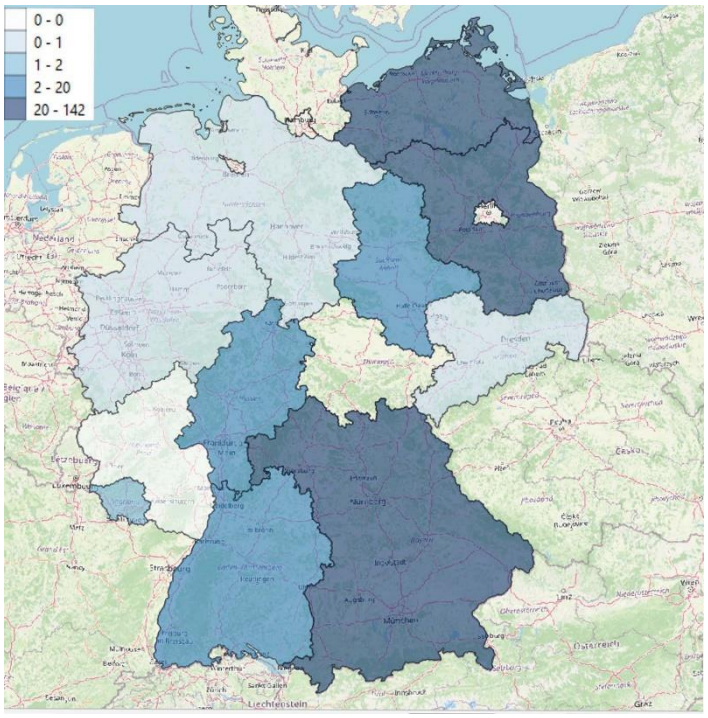

Figure 5. Installed and planned capacity in MWp of agrivoltaic facilities in German states; © OpenStreetMap

Regional differences

A regional disparity is clearly visible in the **figures 3** to **5**. The reasons for the different regional distribution are manifold and have not yet been further examined. On the one hand, the disparity could be due to the federalist system in Germany and, in this context, also the German regulation policy. This allows the states to pursue subsidy policies that are expanding and supplementing federal regulations. Furthermore, differences in agricultural structure are also likely to play a role, for example with regard to the average agricultural area per farm [17]. The average size of a farm in Germany is 63.2 ha per farm [3]. In the northern German states, the farm sizes are larger than in the southern states. Smaller agrivoltaic facilities are therefore to be expected in southern Germany and larger ones in northern and particularly in north-eastern Germany. Recalling the maximum bid (2 MW_P) in the innovation tender and the agricultural structure, it is hardly surprising that almost all supported facilities are located in southern Germany, while construction of larger-scale and economically more profitable facilities are concentrated in north-east Germany.

It is expected that data obtained in the future, through the recurrent design of the survey, may provide more accurate insights into the reasons for regional variation in distribution of agrivoltaic facilities.

Conclusion

The future outlook of agrivoltaics in Germany is positive. National, sub-national and EU policies are increasingly drawing attention to agrivoltaics, creating a more supportive legal- and business environment. This is not only reflected in the projected number of installed facilities within the next year, but also in new, more precise specifications, e.g., from the Federal Energy Grid Agency, which brings clarity and planning security for the double land use of agricultural land with photovoltaics [18]. So far, it is estimated that the number of agrivoltaic facilities will increase from 21 to at least 45 by 2024, while the installed capacity is assumed to increase from 12.46 MW_P to 380 MW_P. The adoption of this novel land use concept shows a remarkable spatial diversity in Germany. This is a great opportunity for the diverse application areas of different agrivoltaic systems. A large proportion of facilities have been planned and realized in southern Germany, including those subsidized under the innovation tender from April 2022. Additional large-scale agrivoltaic facilities are mainly planned in north-east Germany. The realization of agrivoltaic facilities seems to be affected by the interaction of supporting regulatory environments and agricultural structures. The upcoming innovation tender round of 2023 may confirm the assumptions and provide more detailed insights into the necessity and design of targeted subsidies. Based on this, a corresponding funding regime can then be further discussed and developed politically.

Data availability statement

The data of the German Federal Energy Grid Agency is public accessible. The data of the survey is due to its actuality not public accessible.

CRediT authorship contribution statement

Carl Pump: Conceptualization, Data curation, Investigation, Project Administration, Supervision, Validation, Visualization (lead), Writing – Original Draft Preparation. Writing – reviewing & editing (lead). **Max Trommsdorff**: Conceptualization (lead), Data curation, Funding acquisition, Supervision (lead), Writing – Review & Editing. **Volker Beckmann**: Writing – Review & Editing. **Tamara Bretzel**: Conceptualization, Data curation, Investigation, Validation (lead),

Writing – Review & Editing. **Özal Emre Özdemir**: Conceptualization, Data curation, Investigation, Validation. Writing – Review & Editing. **Lisa-Marie Bieber**: Data curation (lead), Investigation (lead), Resources, Validation, Visualization, Writing – Review & Editing.

Competing interests

The authors declare no competing interests.

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