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Photovoltaics in agricultural landscapes: "Industrial land use" or a "real compromise" between renewable energy and biodiversity? Perspectives of German nature conservation associations

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Abstract

Background One common renewable energy source for substituting fossil sources is photovoltaic (PV) systems. However, installing PV systems in agricultural areas can lead to competition with other land uses. These projects, therefore, often encounter problems with social acceptance in affected communities. Especially from the perspective of nature conservation targets, conflicts can arise. These potential differences are still under-researched but represent important knowledge for the societally broadly accepted design of such facilities and their contribution to energy transformation. In this paper, we investigate the perspectives of nature conservationists on PV in the region of Brandenburg, Germany. We comparatively analyse attitudes towards ground-mounted photovoltaics (GM-PV) and agrophotovoltaics (APV). APV combines energy supply and agricultural production on the same land and could thus be a possible solution for mitigating land-use conflicts.

Results We investigated the degree of local acceptability and positive and negative influencing factors through a qualitative text analysis of ten interviews with local representatives and position papers by Nature Conservation Associations. Our findings show a growing consensus around basic assumptions of the need for renewable energies, the prioritised support for PV systems on rooftops over the installation on agricultural land (GM-PV and APV), and the necessity for PV systems to be compatible with nature conservation objectives. Regarding specific site decisions on agricultural land, we find diverging attitudes when comparing the content of position papers and the responses of interviewees. The interviewees advocate taking into account local interests and specific regional conditions, the effects of PV systems on the local environment, and the need for distributional justice. Large-scale plants are locally less accepted than smaller ones and there is a more open attitude towards the expansion of APV than of GM-PV on agricultural land. However, a range of concerns regarding consequences for landscape and biodiversity persists, and further research and clarification is required to address these issues.

Conclusions We conclude that basic ecological standards and the demands of local stakeholders and interest groups should be taken into account when planning, implementing and reviewing PV projects in the future.

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Keywords Ground-mounted PV, Agrophotovoltaics, Acceptability, Attitudes, Nature conservation, Agriculture, Renewable energy, Climate protection

Background

Globally, climate protection has become one of the most urgent political and social challenges of our time. In Germany as well, the topic of energy transition (known in German as the *Energiewende*) towards climate neutrality is central and the use of renewable energies has been widely promoted politically and institutionally, especially against the background of recently claimed intentions to reduce the country's reliance on imported fuels. Germany's *Energiewende* and the associated pressure to rapidly implement more renewable energy-generating systems is taking place mainly in rural areas. In particular, the installation of ground-mounted photovoltaic (GM-PV)[1] and wind turbine parks is space-intensive and has a large-scale impact on landscapes. This leads to competition in rural agricultural landscapes between different land-use demands, such as energy supply, agriculture, forestry, nature conservation, local recreation and tourism. For instance, international targets agreed under programmes such as the European Green Deal, the Conservation of Biological Diversity (CBD) project and the UN's Sustainability Development Goals (SDGs) can be viewed as competing with the goal of expanding the development of renewable energy systems. Strategies to reduce these competing demands often consist of segregating or integrating different land uses. Against this backdrop, various approaches can be distinguished for photovoltaic systems. Whereas GM-PV is part of the segregation strategy (on a land plot, where either agricultural or energy production occurs), agrophotovoltaics (APV) have been discussed as a potential integration strategy because of their capacity to combine energy supply and agricultural production on the same plot of land, thus reducing land-use competition [2] (Fig. 1). In addition, for APVs, further synergies such as the protection of crops by means of solar modules have been promoted [3]. Schindele defines the following main characteristics of APV: (i) maintaining agricultural land; (ii) food production instead of extensification; (iii) protective function through higher elevation; (iv) contribution to the adaptation of agriculture to climate change; (v) increasing the amount of land used; and (vi) being a "physical structure" and not a building [4].

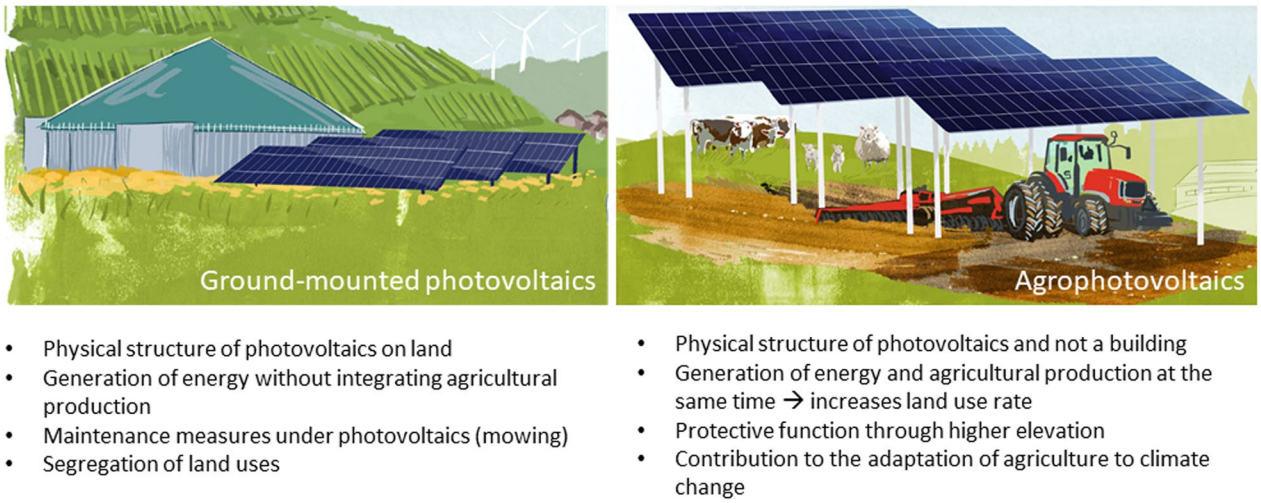

Fig. 1 Characteristics of PV systems in agricultural landscapes: ground-mounted photovoltaics (GM-PV) and agrophotovoltaics (APV), illustration by Stephanie Brittnacher

[1] Ground-mounted photovoltaic installations are defined in the German Renewable Energy Sources Act ("Erneuerbare-Energien-Gesetz") as: "every solar installation which is not on, affixed to or in a building or any other construction which has been erected primarily for purposes other than the generation of electricity from solar radiation energy" [1].

In this situation, where new technologies come up against possible opposition, nature conservation associations (NCAs) constitute one type of actor that has to mark out its position and role so as to adequately represent its interests. Although nature conservation is still these associations' primary objective, they increasingly need to address other issues as well. We assume that diverse and diverging interests among members of, in particular, large NCAs could play a role in how positions are discussed and negotiated. It would, therefore, be valuable to investigate how NCAs adapt their objectives, positions, and programmes to this situation, and to examine the variety of viewpoints they take on climate protection and on the use of GM-PV and APV to achieve this goal.

State of current research

A host of scientific studies focus on renewable energies—especially when it comes to their market-related and technical potential, but also in terms of social acceptance or acceptability[2] towards various energy sources [5–9]. According to Busse and Siebert's review of the scientific literature [5], the publication of papers on the acceptance and acceptability of renewable energies has increased over the last 20 years. The authors identify general factors that influence acceptability-related decisions regarding renewable energies from different research studies, including trust, participation, prior experience and visual aspects. The expansion of PV systems has been recognised as a key contribution to implementing EU initiatives, such as the EU's Green Deal (and its associated recovery plan) and to achieve renewable energy and climate targets [5]. Despite the proposed benefits of initiatives like these, conflicts around land use can arise, especially in the case of large-scale PV installations. Focusing on these types of conflict, interviews in Switzerland with various stakeholder groups (including representatives from NGOs) suggest that a balance between large- and small-scale PV installations could lead to higher social acceptance [5]. Due to an increase in the size and number of PV installations, Scognamiglio [10] argues for putting in place a more integrated GM-PV design that incorporates landscape aspects to minimise "land transformation", enhancing ecological performance and hence gaining more acceptance from members of affected communities. Findings from a recent German survey looking at factors influencing people's acceptance of different types of renewable energy—including PV—show that societal perceptions and attitudes regarding renewables vary widely, ranging from support to indecision to opposition [11].

APV is even less investigated, because this innovation is more recent than GM-PV. In terms of APV, the technology as well as people's perspectives on it has played an increasingly important role in research over recent years. APV is recognized as relevant topic of research and examined in different national contexts [12–14]. In particular, local and market acceptance are seen as essential for delivering sustainable energy and food at the European level [15]. Due to the potential of APV to combine different land uses, as well as to recent developments in APV technology and the diversity of design options relating to it, Toledo and Scognamiglio [16] argue that APV is acknowledged as a possibility for addressing some of the multifaceted challenges arising from climate change. In addition, the authors emphasise a general need for a transdisciplinary approach when developing energy transition projects. Acknowledging the importance of farmers' views on the innovation for a successful diffusion, interviews with experts from the agricultural sector regarding the challenges and opportunities of APV in the US show that its potential benefits are recognised in the combining of agriculture and solar energy [17]. On the other hand, some interviewees also mentioned barriers for adoption, including concerns regarding long-term land viability, economic concerns about uncertainties and compatibility with farmers' day-to-day practices. Interviewed farmers from Turkey display a positive attitude towards APV and a motivational drive especially due to upcoming synergies regarding problems in Turkish agriculture. Yet, institutional shortcomings arise [18]. In further research by means of a survey carried out in the US, Pascaris et al. [19] found evidence of a preference for APV instead of GM-PV under certain conditions—for example, if this resulted in a fair distribution of economic benefits. In 2023, Torma and Aschemann-Witzel [20] conducted an analysis based on semi-structured interviews regarding APV in Germany, Belgium and Denmark to identify barriers to and drivers of acceptance. However, environmentalists were not involved in this study. Especially in Germany—where our case study region is located—researchers have been intensively investigating the potential of this novel technology. Based on a choice experiment with a representative sample of the German population, Gerhards et al. [21] conclude in their conference paper that most respondents prefer a multifunctional land use over spatially separated energy and agricultural production. Additional research has been carried out by Ketzer et al. [22, 23], who analyse the social acceptance from a citizens' perspective on APV in southern Germany. However, reviewing the state of current

[2] For definitions that explain the differences between acceptance and acceptability, see Sect. Theoretical Framework

research suggests that a rigorous evaluation of opinions and perspectives of members of NCAs is still lacking.

Objectives and research questions

Thus, we identified a research gap when it comes to examining the local acceptability of PV systems in agricultural landscapes (including GM-PV and APV), especially by members of NCAs. NCAs represent in first-order nature conservation interests and are an important (counter-)voice in the discourse of sustainability-oriented development, where they are confronted with other "powerful" economic actors and their generally profit-oriented interests. The authors posit that commonly agreed stances and the avoidance of fragmentation into partial positions may be valuable for ensuring a powerful, persistent and continuous representing of the interests of nature conservation in political decision-making.

However, such unified approaches seem to be increasingly difficult against the backdrop of conflicting goals, growing complexities and ambiguities. Contradictions and conflicts about aims can arise between different levels of action and associated interests, for instance between global climate protection and biodiversity conservation interests, on one hand, and local (that is, location-specific) conservation interests, on the other. At the same time, there are still many uncertainties regarding the ecological impacts of PV (including GM-PV and APV), making it difficult to find a unanimous position. As a consequence, NCAs could risk weakening their voice in future policymaking around installing PV systems in agricultural landscapes. It is, therefore, important, we argue, to grasp whether—and under what circumstances—internal differences and disagreements arise from the perspective of NCA members. This study contributes to this.

The aim is to shed light on the need to further analyse (local) environmentalists' attitudes and potential heterogeneity of perspectives within the relevant organisations, especially in terms of varying opinions regarding different projects. To examine these attitudes and members' factors influencing acceptability of PV projects, we need to evaluate possible influences on their perspectives. We address this aim by applying qualitative text analyses to (i) NCAs' public position papers, (ii) expert interviews with people working at different levels of two main German NCAs, and (iii) an expert interview with one regional representative of several environmental organisations working in Brandenburg.

The following research questions structure this paper:

> RQ1: "What factors influencing the acceptability of GM-PV and APV of environmentalists can be identified?
>
> RQ2: Do perspectives of local and regional environmentalists regarding GM-PV differ among interviewees and do these differ from those expressed in their associations' public statements?
>
> RQ3: Do APV lead to a change in degrees of acceptability compared to GM-PV?

Theoretical framework

A much-cited work examining the relationship between acceptance and energy projects (including renewable energy sources and technologies) by Wüstenhagen et al. [24] proposes different dimensions of social acceptance. The authors divide social acceptance into three types: (i) socio-political acceptance, which covers acceptance of technology by the public, key stakeholders, and policy makers; (ii) market acceptance, which refers to acceptance by users/consumers, investors, and intra-firms; and (iii) community acceptance, including aspects of trust and procedural and distributional justice. Our study focuses mainly on socio-political acceptance, because local members and representatives of NCAs are a key stakeholder group when it comes to planning the implementation of GM-PV and APV. However, the second category—community acceptance—also plays a role in our study. Furthermore, it is important to note that Wüstenhagen et al. use the term "acceptance" rather than "acceptability". The former term can be ambiguous: "acceptance" is often used to denote whether people accept or reject something but it tends to presuppose that attitudes and decisions will be positive towards that which is accepted. Therefore, we advocate for a differentiation between the two terms, as proposed by Busse and Siebert [5] and Fournis and Fortin [25]. Although there is no common understanding what both terms mean, we prefer the term "acceptability" when talking about a multifaceted, social and evolving phenomenon, and the term "acceptance" for positive outcomes as opposed to rejections of a proposal. Busse et al. define acceptability as:

> *"a bundle of complex, non-static but mutable decision processes regarding a certain object made by different involved actors. These processes are characterised by the use of value-based arguments and by different acceptability degrees—ranging from rejection to high acceptance or even engagement. […] Within this process, an active reflection on the issue within its context and interaction with others and social norms are required [Lucke 1995]" [26].*

One way to approach such complex phenomena is by carrying out acceptability studies. These should include all the previously mentioned aspects and should also take into account contextual aspects, such as legal and institutional frameworks, planning procedures, systems

approaches, societal factors and technical/scientific considerations (ibid.).

Methods

Case study description

This study includes data collection on the national and regional level in Germany. Therefore, we describe the situation of GM-PV and APV in agricultural landscapes in the context of the country's *Energiewende*, and then the specific regional conditions in the federal state (or *Land*) of Brandenburg.

On the national level, the German government cites the *Energiewende* (the transition to renewable energies) in their coalition agreement as a key part of their work to reach the "1.5°" goal and to abide by the Paris Agreement. Ministers have set out plans to intensively expand PV installations and to remove related barriers. Innovative types of PV technology such as APV that foster more multifunctional types of land use are currently being promoted [27].

The state of Brandenburg aims to be climate-neutral at the latest by 2045. To mitigate climate change, policymakers are aiming for a transformation of the current energy system towards a more climate- and environmentally friendly one, with lower carbon emissions and greater maintenance and safeguarding of biodiversity, for example. The state's Energy Strategy 2040 includes wind and solar power as the foundation for a more secure future energy supply. High expansion targets for PV systems are designed to cover 100% of gross electricity demand based on renewables by 2030 [28]. The planning and installations of all PV systems in agricultural landscapes requires a binding site plan ("Bebauungsplan") and depends on municipal decision-makers to grant permits ("Kommunale Planungshoheit"). In this phase, different stakeholders, including nature conservation bodies, need to be consulted [29]. Recognising the importance of local representatives of NCAs active in the region is thus vital. The following info box (Fig. 2) describes how the NCAs are organised—specifically in Brandenburg.

In comparison with GM-PV, APV systems are still at the embryonic stage of large-scale implementation in Germany [30]. For instance in Brandenburg and northern Germany, large-scale APV projects are still at the planning stage [31]. The state of Brandenburg acknowledges APV as part of its future energy supply with the possibility of creating additional income for farmers [28].

Since we expect that most conflicts with conservation interests will occur during the implementation of large-scale photovoltaic projects (GM-PV and APV), we focus especially on attitudes towards these large-scale designs. Traditionally, Brandenburg has been an energy-producing state. For a long time, large amounts of

Nature conservation associations (NCAs) in Germany:

In 2023, there are 133 accredited long-term NCAs of citizens with various fields of interests such as traditional nature conservation, species protection, and climate protection

By law (§63, "Bundesnaturschutzgesetz"), accredited nature conservation organizations are entitled to speak out regarding planned interferences with nature in order to keep damages as small as possible.

"Landesbüro (anerkannter Naturschutzverbände)" Brandenburg:

- Union of the five NCAs that are active in Brandenburg (NABU, BUND, Grüne Liga, SDW, NaturFreunde).
- Aim: sensible coordination of the involvement of the entitled organizations, effective management of common tasks and to advocate nature's interests in planning projects
- Publication of statements for instance regarding renewable energy projects
- Staff is in direct contact with volunteers in regional & local groups (on-site knowledge)
- Additionally, consultation for citizens' initiatives, municipalities & individuals is offered
- Per year around 900 public statements are released

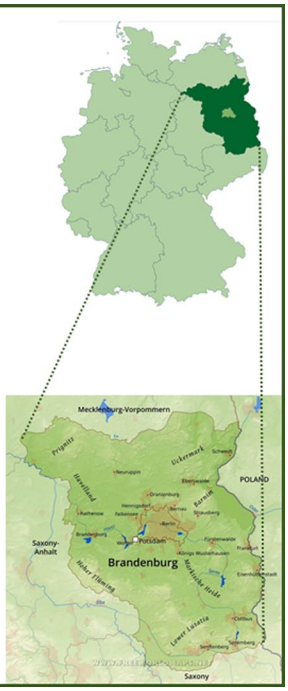

Fig. 2 Info box about nature conservation associations (NCAs) in Germany and the tasks of the "Landesbüro" in the state of Brandenburg (Source: Landesbüro anerkannter Naturschutzverbände [26] and Umweltbundesamt [27, 28])

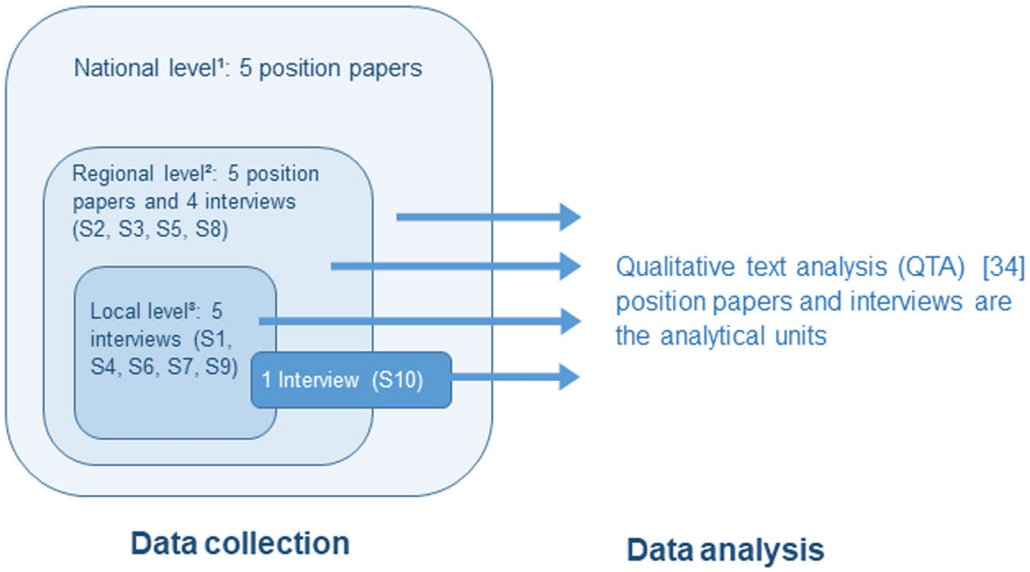

Fig. 3 Nested case study approach for the national[1] (Germany), regional[2] (state of Brandenburg) and local[3] (local groups in Brandenburg) level

energy based on coal were produced and exported. The plan is for renewables to eventually replace fossil energy sources [32]. Because the state has many sparsely populated areas, and due to high energy demand and energy prices, municipalities and farmers in Brandenburg are facing a run of investors searching for land suitable for implementing PV projects [32, 33]. The largest PV park in Germany is currently located in Brandenburg [34]. Due to their profitability, PV parks are increasingly being planned that go beyond the current criteria for funding set out in the German renewable energy law (ibid.). However, the large number of conservation areas in Brandenburg is expected to give rise to potential conflicts over land use between advocates for the planned renewable energy projects and those tasked with nature conservation [32].

Research design

We aimed to address the research questions presented above by applying a nested case study approach [35] with an interpretive and qualitative research design [36]. Because ascertaining the attitudes and perspectives of nature conservationists regarding GM-PV and APV on agricultural land is a complex task, where little prior evidence is known, a qualitative research design was chosen for gathering and analysing empirical data. The research design consists of three sequential steps: (i) a review of ten position papers from several German NCAs (RQ2); (ii) nine qualitative semi-structured interviews with representatives of NABU and BUND on regional and local levels (RQ1–RQ3); and (iii) one qualitative semi-structured interview with a representative of the overarching "Landesbüro Brandenburg" (RQ1–RQ3). The public statements and the interviews were analysed by carrying out qualitative text analysis (QTA), based on the work of Kuckartz [37]. With these three steps we addressed the following objectives: (i) creating a scientifically valid overview of the publicly stated opinions regarding GM-PV and APV and the potential homogeneity or heterogeneity of these opinions; (ii) generating insights into factors that influence the acceptability level of regional (federal state) and local representatives and the potential divergences or overlaps among these levels; and (iii) analysing the interviewed responses of one regional representative of several environmental organisations working at the "Landesbüro" Brandenburg on various issues. Figure 3 illustrates the research design.

Data collection

For step (i) we reviewed the position papers of German NCAs (from national and regional levels) released from 2021 to 2022. We chose this material based on a preselection of relevant active associations working on general nature conservation issues and not limited to any specific project. From these, those with high membership numbers (to identify representative organisations) were chosen. We gathered the most up-to-date position papers in connection with photovoltaics and solar energy. To ensure relevance, only publications from the last 5 years were considered. Data collection for the QTA was completed by the end of 2021, so any documents from after that date are not considered. Additional file 1 provides an overview of the analysed material (position papers). All

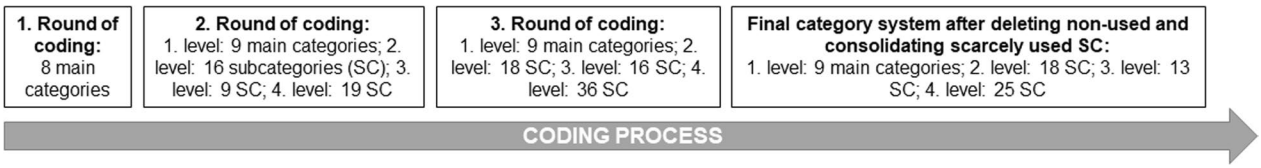

Fig. 4 Coding process

material addresses PV systems. In eight out of ten cases it is the central topic. In contrast to GM-PV, APV systems still play a minor role in these publications.

In step (ii), we conducted qualitative expert interviews [38] with representatives of two of the largest and most relevant German NCAs—NABU (Naturschutzbund Deutschland) and BUND (Bund für Umwelt und Naturschutz Deutschland). Nine interviews took place in July 2022, and the expert interview with the representative from the overarching Landesbüro in January 2023. These were conducted face-to-face, by telephone or via video link. Additional file 2 shows the characteristics of the interviewees (S1–S9). All interviews were semi-structured. Thus, a prepared interview guideline concerning context-related questions and literature-based questions (based on work by Busse and Siebert [5] and Dunk et al. [39], as well as on publications from Fraunhofer ISE [3], BUND [40], and NABU [41]) ensured a mix of thematic guidance and scope for new information [42]. The questions were structured into five main topics personal background information; attitudes towards GM-PV and large-scale projects in Brandenburg; APV and land-use conflicts; perspectives on public opinions by NABU/BUND; closing questions) and a few subsidiary topics (see Additional file 3). Because the interview with the representative of the overarching organisation was conducted after we had completed the analysis of the NABU and BUND members' responses, it was possible to update and condense the interview guideline. Questions that did not lead to relevant insights were omitted from the final interview that was intended to support the findings from previous ones. The guiding questions used can be found in the supplementary material. The interviews were fully recorded and transcribed verbatim following pre-set transcription guidelines.

Data analysis

To assess the public position papers and the interviews, we applied the QTA procedure devised by Kuckartz [37] and complemented this with information on software-assistance by Rädiker and Kuckartz [43]. The first qualitative text analysis of collected publications was done manually and the interviews were evaluated using MAXQDA. At first, we applied the structured type to achieve a thematic analysis using a hierarchical structure (main categories and sub-categories). We started with concept-driven (deductive) categories, created from previous research and interview material, and eventually added data-driven (inductive) categories. Figure 4 depicts the coding procedure. In the additional material, a profile matrix depicts the main messages of the codings in a condensed and structured way. This forms the basis of the content analysis for each analytical unit or each topic [37].

In a later step, we complemented the analysis with an evaluative analysis to determine the degree of acceptability decisions. Steps such as the ordinal formulation of characteristics (in this case the acceptability decisions as formulated by Sauer et al. [44]), the allocation of statements and the carrying out of group evaluations followed the procedures set out by Kuckartz [37]. The expert interview was analysed with the same procedure (three rounds of deductive/inductive coding) and the same category system. It was necessary to create three new codes in addition to the existing category system (two negative influencing factors and one suggestion for improvement). To assess the similarity of the perspectives with, on one hand, the public statements of several organisations and, on the other, the statements of individual members, this structured type of analysis seemed a valid approach. Statements given by S10 were deemed to be current official opinion—specifically for the Brandenburg region.

Results

The results section is divided according to the research questions. A summary of the content of the interviews and position papers is illustrated in profile matrices in the additional material (Additional file 4). The original quoted statements and their translations can be found in Additional file 5.

Factors influencing the acceptability of GM-PV (RQ1)

The analysis resulted in a list of aspects that were either positive or negative acceptability factors—for instance, perceived trust enhances acceptance, whereas a lack of trust reduces acceptance. Figure 5 depicts these acceptability factors found in the interviews.

The members of NABU and BUND interviewed highlight a broad range of aspects to consider. They point out

- Negative factors	Factors influencing Acceptability (Attitude level)	+ Positive factors	Conditions for Acceptance
Use of valuable areas (agriculture, recreation, nature conservation)	Choice of location *(deductive)*	Use of less valuable areas (for agriculture, recreation, nature conservation)	Prioritizing PV on roofs & sealed areas *"But despite all this, for photovoltaics you should first and foremost really check what you can do with the existing roof surfaces." (S10)*
Excessive land consumption/ fragmentation effect	Effects on land use and structure *(inductive)*	Avoiding fragmentation / create corridors	Dividing large plants/small-scale projects: *"That from a certain area size onwards, these connecting corridors (…) are taken into account and that it is inevitable that there is not one large installation that is completely fenced off (…)"* (S2)
High interference with surrounding landscape (esp. for large plants)	Interference with surrounding landscape *(deductive)*	Low interference in comparison to other forms of energy production	Monitoring of the installations/compensation measures " (…)sometimes there is a lot in the document and sometimes there are also good, useful compensation measures listed, but the question is whether they are all implemented (…)" (S10)
Negative influence on local nature/missing biodiversity gain when implemented	Effects on local nature/ biodiversity *(inductive)*	Possible extensification/ enhancing biodiversity*	Considering locational factors/nature compatibility *"So there are a number of things that can simply be done. And as I said, you have to look at what the natural space offers, what makes sense, where such biodiversity corridors can be created again. You have to work with this in order to design it well."* (S2)
Missing participation and integration	Participation and integration of diverse actors *(deductive)*	Enabling different stakeholders to have a say in process	Early participation of local actors: *"We stand for a citizen-owned energy transition"* (S5)
Distrust in used material & actors	Attitudes towards used material & actors *(inductive)*	Trust in used material & actors	Creation & distribution of positive examples *"(…) that both sides can go in with more trust and (…) create positive examples. (…), where you can see that if you do it well, something good will come out of it in the end."* (S2)
Perceived unfair distribution of costs & benefits	Costs and benefits = distributional fairness *(deductive)*	Perceived fair distribution of costs & benefits	Avoiding clusters of renewable energies in one region: *"And let's say someone gets the idea that the landscape is polluted anyway (…), people have to think, somehow, they'll get everything."* (S1)
-	Form of generating renewable energy *(inductive)*	Low-emission energy production/ energy transition/ energy sovereignty	Investments/changes necessary *"Incentives in terms of subsidies and also with regard to the formal conditions that have to be fulfilled in order to feed electricity from photovoltaic systems into the grid or to use it oneself."* (S8)
Missing communication/ decisions over citizens' heads	Communication of information *(deductive)*	Successful communication	Communication with local actors *"And we would wish that (...) the people (...) are not presented with accomplished facts"* (S2)
Missing benefits for affected local individuals & municipalities	Socio-economic factors, e.g. job opportunities *(inductive)*	Benefits for affected local individuals & municipalities	Distributional Fairness *"(…) the municipalities should also benefit from the energy transition. (…) "Well, a certain area will be lost here for natural recreation, but we will compensate you by putting up a few benches in the estate park or doing something so that other areas can be better used for recreation."* (S3)
Maintain high standards/take time ↔ faster procedure/ reducing bureaucracy	Planning procedure *(inductive)*	Maintain high standards/take time ↔ faster procedure/ reducing bureaucracy	Controlling expansion/clear criteria *"(…) it would make sense for these sites to be selected according to certain criteria. And not according to the "first come, first served" principle (…)"* (S8)
Senseless expansion	Holistic view on expansion *(inductive)*	Sensible expansion/ complement of measures	Improve energy savings, storage & transmission potential *"That they are built where there is also a high demand for energy or where there is the capacity to transport the energy or create the capacity to transport the energy (…)"* (S9) *"(…) talk much more about how we want to live in the future and how we want to do business in the future"* (S8)

Fig. 5 Factors influencing degrees of acceptability and related conditions for acceptance. According to their frequency of occurrence, the factors are arranged in descending order

a lack of trust in decision-makers, their past experiences of nature conservation aspects not being considered impartially and the predominant focus put on economic interests. Some positive consequences of solar parks on biodiversity are acknowledged in theory, although some interviewees questioned the long-term benefits when it came to practical implementation. The regional "Landesbüro" representative for various environmental associations (S10) mainly focused on the negative consequence of losing valuable land that should preferably be used for agriculture or to sustain biodiversity. It was mentioned that this impact is specifically strong in Brandenburg, since large-scale projects are common and land for agricultural use is becoming a scarce and much-in-demand resource.

Heterogeneity or homogeneity in perspectives (RQ2)

In this section, we focus on the potential heterogeneity or homogeneity of perspectives (i) among respondents between the different geographical levels, (ii) among interviewees at the same geographical level, and (iii) between the interviews S1–S9 and public opinions (position papers), as well as between the perspective of the regional representative for various environmental associations (S10) and the statements put forward in the position papers.

Results suggest that almost all interviewees agree on a few fundamental values: we see homogeneity in arguments such as the need to develop renewable energies for climate protection and energy sovereignty in Germany. PV on roofs and sealed areas are always prioritised over GM-PV on agricultural land and cited as an option that does not interfere excessively with the surrounding environment. We found agreement that the expansion of PV systems in agricultural landscapes (including GM-PV and APV) can give rise to conflicts between nature conservation and climate protection. Certain areas such as forests and nature conservation areas should be kept free from development. The representatives in Brandenburg are especially critical of large-scale projects and the effects on landscapes and rural areas. There is a degree of heterogeneity of opinion between the interviewees regarding how they evaluate the conflicting demands, the accepted interference with nature in the name of long-term climate protection and the preferred design, the areas used and location of the PV plants. All interviewees call for

climate-protection measures that take into account the needs of nature and that enhance biodiversity as much as possible. Interviewees' confidence in the supposed benefits to biodiversity varies markedly between themselves and in comparison with the assertions featuring in position papers. Most interviewees refer to existing PV parks or other renewable energy projects to emphasise their attitudes. Most of them also underline the need to monitor projects and research their side-specific factors and tend not to express either complete rejection or unquestioning support. The evaluative text analysis suggests that acceptability decisions when it comes to PV parks are influenced neither by the geographical level (local ↔ regional) nor by membership in a particular NCA. We found high levels of acceptance and of rejection/opposition on both geographical levels. The following quotes from local members of the NCAs illustrate the diversity of opinion even on the same geographical level:

- "Just because it's renewable energy, every nature conservation association has to think it's great. That actually can't be the case." (S1)
- "These are outdoor structural and commercial facilities, in the open countryside, which basically don't belong there. Of course, I don't want to reject them with that." (S4)
- "The little orchid back there where the photovoltaic plants are or some other plant worth protecting will lose out. That's how brutally I put it. But first, of course, we have to try to find solutions." (S6)

Furthermore, interviewees exhibit a range of attitudes regarding GM-PV and APV, which results in varying degrees of acceptability that can be assigned: high acceptance was expressed by S3 and S6, whereas rejection was stated by S7. However, the most common degree of acceptability is "conditional acceptance". Conditions for increasing the likelihood of acceptance are mentioned both in the interviews and in the position papers. We found conformity in demands for future projects such as the need for clear and transparent communication from the start, the active participation of different local stakeholders in the planning process, impact compensation for municipalities, solar parks to be designed in cooperation with NCAs, and sensible compensatory measures complemented by regular independent controls.

When comparing the statements of the regional representative (S10) with publicly available position papers and the other interviews, we found that this interviewee's attitude to large-scale GM-PV is much more critical than the national and regional position papers we assessed. The interviewee's arguments supported statements from the other interviews: S10 stressed the unintended side-effects of the installations on nature over the long term and the loss of fertile land for agriculture and natural dynamics. As with the other interviewees, S10 called for more research on the consequences and for scientific monitoring of PV plants.

We also looked at the conformity or discrepancy between lines of argument in the position papers (published between 2019 and 2021) and statements expressed by interviewees (2023). However, the analysis pointed to marked similarities between the opinions set out in the various position papers. The argumentation of the different organisations on the regional and national levels is consistent. We found a clear tendency in the position papers to prioritise PV on rooftops and sealed or devastated soils. GM-PV is also welcomed in addition to PV on roofs when taking into account criteria governing nature conservation and climate protection. This is mainly justified on the basis of a perceived possibility for "extensifying land" instead for using these sites for more intensive agricultural production or other land uses. The hope of the NCAs is that such an extensivation of land use could provide biotopes for insects and small mammals and, thus, enhance biodiversity conservation. Many interviewees cited the need for consistent regulation, more investment and further research. Many acceptability factors mentioned by interviewees (Fig. 5) overlap with those appearing in position papers. However, it is notable that the regional and local representatives mentioned additional concerns surrounding GM-PV, such as conflict over land use and potential degradation of the local ecology, e.g., through fragmentation of habitats. Other considerations were evident in the interviews but often downplayed in the publications: visual impacts on landscapes scenery; a lack of trust in the fairness and independence of some actors, a sceptical view of the genuine decision-making power of municipalities; and a divergence between proposed site plans and their real-world implementation. The latter refers particularly to whether compensatory measures can be better regulated and adherence to these monitored over the long term. Anxieties about an increase in (overly) large-scale projects in rural areas were expressed in nearly all the interviews.

APV: changes in degrees of acceptability (RQ3)

Finally, we examined perspectives on APV from the conservation angle. We looked at the potential of APV technology to be better accepted compared to traditional GM-PV on agricultural land as it can supposedly allay existing concerns. The NCA position papers rarely address APV, because it is a relatively novel technology. The organisations that thematise it remain vague in their public pronouncements and emphasise the potential for

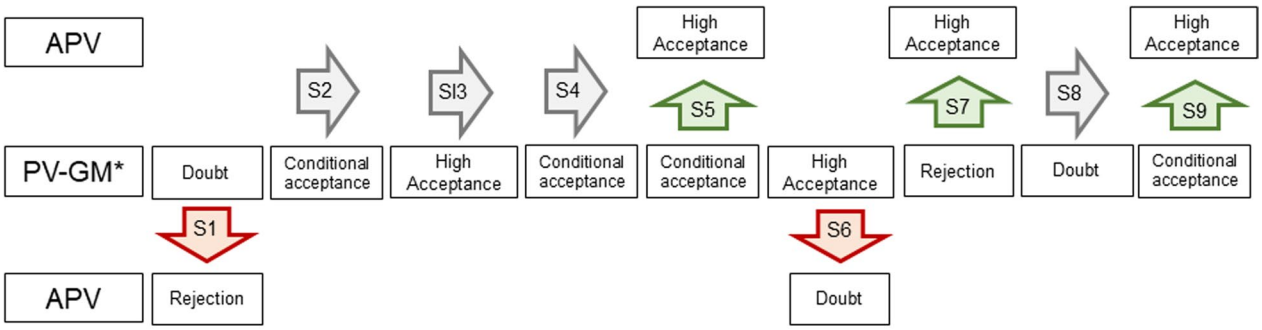

Fig. 6 Changes in degrees of acceptability from PV-GM to APV

combined effects of such multifunctional landscapes. In contrast, interviewees' opinions were much more differentiated. As an example, the regional representative of several environmental organisations ("Landesbüro") refrained from expressing clear opinions about the innovation. Nevertheless, this interviewee welcomed the idea of maintaining agricultural production using APV instead of GM-PV. Simultaneously insecurities and concerns regarding APV and the same requirements regarding compatibility with nature and project planning as for GM-PV are mentioned. Interviewees shared their doubts about this issue because of a lack of information and experience. In general, even if doubts were expressed, most supported the idea and recommended further research. Interviewees also stated that generally research insights should be communicated to the wider public.

In terms of interviewees' conditional acceptance and doubts regarding traditional GM-PV systems on land, some acknowledge APV as a contribution to resolving conflicts around land use between the needs of agriculture and those of energy production. However, in the words of one representative (S8): "Yes, one [conflict] will be solved, but not others." Several respondents mention the emergence of new conflicts or the risks of exacerbating existing problems, such as lack of ecological connectivity because of the fencing off of solar parks. Some were concerned about a growing visual impact on the landscape when high-mounted APV are installed. A general disadvantage of APV was seen in the fact that the claimed benefits of substituting agriculture with GM-PV, such as extensification, soil rehabilitation and biodiversity, do not come to fruition.

The evaluative analysis of degrees of acceptability shows that interviewees' attitudes to GM-PV as compared to APV are lower only in two cases (Fig. 6). For the majority of cases, degrees of acceptability are the same or higher, though we found no evidence for a pattern of agreement between the views of interviewees. The BUND members interviewed rate the technology more highly than do the interviewees from NABU.

Assessments vary from "industrial agriculture", "science fiction" and "horizontal electricity towers" (S1) to "be[ing] a real compromise" (S3) and a "great hope" (S5). With regard to conditions in Brandenburg, S3 said that "the soil quality index values are a bit too low for that [APV]".[3] To summarise, most of the nature conservationists interviewed seem to be open to the idea of APV installations. Nevertheless, interviewees mentioned still unaddressed questions and recommended that issues surrounding the planning and implementation processes of projects that reduce acceptance should be addressed in further studies.

Discussion

We now compare findings from the interviews with other study results in the relevant research field. Busse and Siebert [5] derived from a literature review the following factors influencing the acceptability of renewable energies in land-use contexts: participation of different stakeholders; prior experience; trust in decision-makers; distributional fairness; and economic and aesthetic aspects. Most of these factors were also mentioned by our interviewees as relevant to their acceptability decisions. In light of recent studies on GM-PV [10] and APV [16, 17, 46], we conclude that these factors are of a general nature and also play a key role regarding the acceptability of GM-PV and APV and for different stakeholder groups. A representative study on the societal perception of the Germanys *Energiewende* [11] has given evidence of a variety of opinions and differing degrees of indecisiveness regarding GM-PV.

[3] Since 1934, productivity of land in Germany has been expressed in numbers up to 100 [45]

Criticisms by German citizens match our results and include the issue of land consumption and negative aesthetic impacts on the landscape. We also found overlaps when it came to suggestions for the planning process, mainly relating to the need for procedural and distributional fairness. However, some findings differ from ours: the importance of individual financial compensation or economic benefits for locals, for example, through creating jobs in rural areas, is emphasised by Sonnberger and Ruddat. Meanwhile, aspects relating to nature conservation seem to be more important for our interviewees than for the general, non-specialist public in Germany (as indeed we suspected). Concerns and suggestions that could raise the likelihood of acceptance—similar to those identified in our study—are also mentioned in two qualitative research studies, where workshops were held with German citizen on the theme of APV [22, 23]. The inclusion of a range of stakeholder groups and their early involvement in further planning processes are needed [20]. For large-scale APV plants, deficits were identified in terms of visual impacts on the landscape and the risk that affected areas will be less attractive for recreation (ibid.). As we found in our analysis of position papers and interviews, the workshop participants stated a preference for PV on roofs and sealed areas rather than having any PV system park out in the open landscape. This preference has also been identified by Späth et al. [47] for GM-PV in Switzerland and by Torma and Aschemann-Witzel [20] for APV in Germany, Belgium and Denmark. Spät et al. [47] also draws attention to the issue of PV parks' potential scale by suggesting that "renewable energy expansion should preserve a balance between large-scale and small-scale photovoltaic power development to be socially acceptable amongst a broad spectrum of stakeholders." However, in our empirical study the majority rejects large scale GM-PV parks, although some acknowledge the economic benefits of large parks and express conditional acceptance when environmental compatibility is considered. While our analysed position papers of nature conservation NGOs also favour the use of rooftops, they do not specify the size of plants, as some of the interviewees did. Comparable to our results, Ketzer et al. [22] focussed on attitudes towards APV and found no clear rejection or acceptance but identified still unaddressed issues regarding the influence of APV installations on yields and ecological aspects. Their workshop participants advocated designs adapted to the landscape that also took into account local knowledge, more decentralised forms of energy production, and a more regulated and restricted expansion of APV in general. In contrast to our results, where APV is viewed with some scepticism, a recent study from the USA [19] suggests that a majority is likely to accept solar projects in their community when APV is installed, as long as this leads to economic gains for farmers and communities, is located on private property and existing agricultural land, does not result in conflicts with local interests, and when a fair distribution of economic benefits occurs. In line with US citizens, US experts mainly see potential benefits in the dual land use that can arise when applying APV [17]. These experts also mention the concerns and uncertainties of particular interest groups: for example, farmers cite economic concerns and compatibility of their land with PV systems (ibid.). However, because we interviewed members of NCAs, our results have a stronger focus on concerns regarding biodiversity than the findings of most other studies.

Besides the overlapping results with other studies regarding the demand to involve different stakeholders in planning procedures, to secure distributional justice and to acknowledge the need for renewable forms of energy, we provide novel insights about the particular perspectives and concerns of NCA members at local and regional (and to some extent national) level.

However, we did not find evidence that the degree of acceptability within NCAs is influenced by the geographical level at which they operate. More precisely, whether interviewees were active in local groups or at a more regional level did not seem to have an effect on their attitude. Although our participants were interviewed as environmental experts, their statements cannot be completely separated from their opinions and attitudes as people living in affected municipalities. Regarding the NCAs in national climate-change adaptation and mitigation programmes (such as Germany's *Energiewende*), it is worth to mention that they are confronted with a new and challenging situation: currently, these organisations occupy an area of tension between the "original" association's interests—promoting nature conservation—and the need to tackle climate change. Considering their attempts to position themselves as "balanced", it is not yet clear how the structures and internal processes—especially in larger NCAs—will develop. Our suggestion is to consider different opinions inside large NCAs to counteract the risk of associations' splitting into factions. Even if all members have the same overall aim to protect nature and the environment, some interviewees pointed to dissatisfaction within their organisations. In our view, this could delegitimise the arguments put forward in position papers. The extent to which position papers are supported by NCA members remains unclear. Do they represent only a minimal consensus among members? However, a harmonisation of diverse opinions can hardly be reflected in position papers. Because local

NCAs' members often express critical opinions about GM-PV and APV, this might lead to nature conservation interests being instrumentalised to bolster local opposition to renewable energy projects. Based on our results, we found that PV systems are not rejected per se but that nature conservationists support the *Energiewende* only on condition that their compatibility with local ecosystems is genuinely considered and preserved.

We next want to shed some light on the significance of our results for the federal state of Brandenburg. In recent years, the installation of solar parks in the state of Brandenburg has increased rapidly. In addition, the situation will continue to gain momentum, since the expansion of solar parks is also supported by federal-state policies as an option for attaining low-emission energy use and thus to achieve climate neutrality by 2045.[4] As mentioned above ("Case study description"), Brandenburg offers huge potential for putting in place renewable energy systems due to its extensive contiguous areas and relatively easy access to it. In contrast, Federal states such as Bavaria with different land use structure might be less attractive as sites for large-scale solar parks. We assume that this is why our interviewees from Brandenburg were particularly worried about the potential increase in the number of large-scale PV parks and the associated visual impact on landscapes, but this was rarely alluded to in position papers at the national level. Comparative case studies that contextualise the situation would need to be undertaken in a variety of German states to examine whether our assumption is valid. The large scale of GM-PV and APV installations is seen by many local people as a major concern. This may be a barrier to widespread acceptance: for instance, we showed that attitudes are predominantly influenced by people's experiences with and perceptions of particular local projects. At the same time, this study also offers the opportunity to examine the acceptability by local stakeholders of such large-scale GM-PV and APV parks and their effects on biodiversity and agricultural production, as well as their impact on landscapes. Our study's findings suggest that analysing local and regional acceptability matters: its results could be incorporated into regional planning processes that include consultations with environmental organisations as one type of regional interest group. This could help to promote policy aims and increase local acceptability, improve the design of GM-PV and APV installations and ease barriers to acceptance.

Although our qualitative study has shown the value of in-depth research for addressing complex phenomena, it does have limitations that could inform the design of further research. It should not be assumed that the results are generalizable to other cases or that they will have universal validity, because they are context-dependent and may change over time. For instance, we could only incorporate a small number of position papers stating detailed about APV, because it is a relatively novel technology. Therefore, changing framing conditions in terms of technological progress or political regulations would need further analysis, because our evaluative qualitative analysis already indicated changes in acceptability degrees when applying APV instead of GM-PV. Such changes in acceptability over time have been argued by other studies [5]. A comparison of data collected at different times but relating to the same region is, therefore, also recommended. In addition, future studies would be of value once APV has become more widely known among stakeholders and when more practical examples and new position papers focussing in-detail on APV are available.

Conclusion

We provided insights into the attitudes of local and regional nature conservation representatives on a highly politicised issue—the large-scale implementation of PV systems in rural areas in general and on agricultural land in particular. By means of the German case study region of Brandenburg, we were able to show that members of the interest group we studied have heterogeneous perspectives on PV systems installation on agricultural land (including GM-PV and APV). Nature conservationists are not a homogenous group—there is neither unconditional support nor uncompromising rejection in our results. However, conditional acceptance seems to be pervasive. Conditions for an increase in acceptability (for example, installing systems initially on roofs, early involvement of affected stakeholders) were mentioned by many interviewees and should be considered in future planning procedures to encourage local acceptance. Decision-makers should thus pay heed to suggestions in NCAs' position papers for planning procedures and solar park designs that increase the likelihood of acceptance. Nature conservation organisations can advise on environmentally friendly design possibilities that optimally combine nature conservation and climate protection. Even when NCA position papers claim public support for GM-PV and APV, it is still necessary to take on board individual and local perspectives. As factors such as the location and extent of planned sites, as well as specific regional conditions, seem to play a role, analysing the context, concerns and demands of local stakeholders should be undertaken at an early stage.

In addition to GM-PV, APV is likely to become a key ingredient of the future energy recipe in Germany and

[4] https://mluk.brandenburg.de/mluk/de/klimaschutz/klimaschutz/erneuerbare-energien/

Brandenburg. APV systems are a promising solution to reduce land use competition between energy supply and agricultural production but could at the same time reduce the opportunity to extensify land use or rehabilitate biodiversity. However, our study revealed that opinions are currently still vague and based on sketchy knowledge. Many issues remain unresolved, for instance regarding long-term consequences, and more research on APV's impact on nature and landscapes is, therefore, needed. In addition to constant and continuous monitoring of demonstration and experimental plants, APV-related technologies and plant designs could be further developed in an open innovation process that includes participation from stakeholders. Listening to and seriously including local environmentalists for the purposes of knowledge co-production could help to increase local acceptance and lead to long-term satisfaction with solar projects when most people are open towards the need for, and advantages of, APV. Based on local experiences there is often a mistrust of decision-makers, as the following quote from an interviewee shows: "The problem is that investors always look for the most profitable, for the maximum profit. In addition, sometimes, the best solution—the one with the fewest conflicts of objectives—is the one that is not the most profitable". To generate more local acceptance, positive examples that consider several interests need to be created, particularly when it comes to biodiversity issues. Biodiversity aspects are naturally a key focus in our study, but many influencing factors and demands overlap with research results in other contexts, regions, or among other social groups. This gives relevance to our results that are already known (in science and also to political voices). However, they need to be put into practice to allay the scepticism of local nature conservationists. It is thus important to identify objective specialists within the planning process who can build trust. Conflicts around land use will increase in future if policymakers cannot find long-term approaches that involve compromises between competing interests and that ensure compensation for affected parties. It will not just be a question of which renewables we can make use of to achieve climate goals, but also of how we imagine and shape our future: "Yes, so my first wish is that we talk much more about how we want to live in the future and how we want to do business in the future in view of the climate crisis, and that we discuss, discuss more strongly, where we can cut back in our luxury world. (…) and not just painting it green" (S8).

Abbreviations

APV	Agrophotovoltaics
EU	European Union
NCA	Nature conservation association
GM-PV	Ground-mounted photovoltaics
QTA	Qualitative text analysis
USA	United States of America

Supplementary Information

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Additional file 1: Material for QTA on public position papers.

Additional file 2: Characteristics of interviewees.

Additional file 3: Interview guiding questions.

Additional file 4: Original quotes used in the manuscript and their translations into English.

Additional file 5: Profile matrix of the analytical units included in the nested case study.

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Author contributions
JH, MB, KM and JZ conceptualized the research design. JH conducted the interviews. KM and MB supervised the data collection. JH analysed the data. MB and JZ supervised the data analysis. JH, MB and JZ wrote the manuscript. JH and MB prepared the figures and supplements. All authors reviewed the manuscript.

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Availability of data and materials
The data sets generated and analysed during the current study are not publicly available due protecting confidentiality of sensitive information but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Before interviews were conducted, an interview consent form was provided to all participants. Each participant signed a consent letter to participate in the interview. Ethics approval is not applicable.

Consent for publication
All authors consent to publication.

Competing interests
The authors declare that they have no competing interests.

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References

1. Bundesministerium für Wirtschaft und Klimaschutz (2017) Renewable Energy Sources Act (EEG 2017). https://www.bmwk.de/Redaktion/EN/Downloads/renewable-energy-sources-act-2017.pdf?__blob=publicationFile&v=3
2. Weselek A, Ehmann A, Zikeli S et al (2019) Agrophotovoltaic systems: applications, challenges, and opportunities. A review. Agron Sustain Dev. https://doi.org/10.1007/s13593-019-0581-3

3. Fraunhofer ISE (2022) Agri-Photovoltaik: Chance für Landwirtschaft und Energiewende: Ein Leitfaden für Deutschland|Stand April 2022. https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/APV-Leitfaden.pdf. Accessed 09 Nov 2022
4. Schindele S (2021) Nachhaltige Landnutzung mit Agri-Photovoltaik: Photovoltaikausbau im Einklang mit der Lebensmittelproduktion: Szenarioanalyse zur Inanspruchnahme landwirtschaftlicher Nutzflächen durch Photovoltaik in Deutschland bis 2050. GAIA Ecol Perspect Sci Soc 30:96–105. https://doi.org/10.14512/gaia.30.2.7
5. Busse M, Siebert R (2018) Acceptance studies in the field of land use—a critical and systematic review to advance the conceptualization of acceptance and acceptability. Land Use Policy 76:235–245. https://doi.org/10.1016/j.landusepol.2018.05.016
6. Cousse J (2021) Still in love with solar energy? Installation size, affect, and the social acceptance of renewable energy technologies. Renew Sustain Energy Rev 145:111107. https://doi.org/10.1016/j.rser.2021.111107
7. Rodríguez-Segura FJ, Osorio-Aravena JC, Frolova M et al (2023) Social acceptance of renewable energy development in southern Spain: exploring tendencies, locations, criteria and situations. Energy Policy 173:113356. https://doi.org/10.1016/j.enpol.2022.113356
8. Enserink M, van Etteger R, van den Brink A et al (2022) To support or oppose renewable energy projects? A systematic literature review on the factors influencing landscape design and social acceptance. Energy Res Soc Sci 91:102704. https://doi.org/10.1016/j.erss.2022.102740
9. Ali M, Irfan M, Ozturk I et al (2023) Modeling public acceptance of renewable energy deployment: a pathway towards green revolution. Econ Res 36:2159849. https://doi.org/10.1080/1331677X.2022.2159849
10. Scognamiglio A (2016) 'Photovoltaic landscapes': design and assessment. A critical review for a new transdisciplinary design vision. Renew Sustain Energy Rev 55:629–661. https://doi.org/10.1016/j.rser.2015.10.072
11. Sonnberger M, Ruddat M (2016) Die gesellschaftliche Wahrnehmung der Energiewende: Ergebnisse einer deutschlandweiten Repräsentativbefragung. Universität Stuttgart
12. Abdulmouti H, Bourezg A, Ranjan R (2023) Exploring the Applicability of Agrivoltaic System in UAE and Its Merits, Dubai, United Arab Emirates
13. Ağır S, Derin-Gure P, Senturk B (2023) AgroPV's potential opportunitites and challenges in a Mediterrean developing country setting: a farmers perspective
14. Junedi MM, Ludin NA, Hamid NH et al (2022) Environmental and economic performance assessment of integrated conventional solar photovoltaic and agrophotovoltaic systems. Renew Sustain Energy Rev 168:112799. https://doi.org/10.1016/j.rser.2022.112799
15. Chatzipanagi A, Taylor N, Thiel, Christian, Jaeger-Waldau, Arnulf et al. (2022) Agri-photovoltaics (Agri-PV): how multi-land use can help deliver sustainable energy and food. European Commission. https://publications.jrc.ec.europa.eu/repository/handle/JRC129225
16. Toledo C, Scognamiglio A (2021) Agrivoltaic systems design and assessment: a critical review, and a descriptive model towards a sustainable landscape vision (three-dimensional agrivoltaic patterns). Sustainability 13:6871. https://doi.org/10.3390/su13126871
17. Pascaris AS, Schelly C, Pearce JM (2020) A first investigation of agriculture sector perspectives on the opportunities and barriers for agrivoltaics. Agronomy 10:1885. https://doi.org/10.3390/agronomy10121885
18. Agir S, Derin-Gure P, Senturk B (2023) Farmers' perspectives on challenges and opportunities of agrivoltaics in Turkiye: an institutional perspective. Renewable Energy 212:35–49. https://doi.org/10.1016/j.renene.2023.04.137
19. Pascaris A, Schelly C, Rouleau M et al. (2021) Do agrivoltaics improve public support for solar photovoltaic development? Survey Says: Yes!
20. Torma G, Aschemann-Witzel J (2023) Social acceptance of dual land use approaches: stakeholders' perceptions of the drivers and barriers confronting agrivoltaics diffusion. J Rural Stud 97:610–625. https://doi.org/10.1016/j.jrurstud.2023.01.014
21. Gerhards C, Reker S, Paskert V et al. (2022) The Agri4Power concept: a win–win situation for renewable energy generation and sustainable agriculture. In: Agrivoltaics2021 Conference: Connecting Agrivoltaics Worldwide. AIP Publishing, USA, p. 130001
22. Ketzer D, Schlyter P, Weinberger N et al (2020) Driving and restraining forces for the implementation of the Agrophotovoltaics system technology—a system dynamics analysis. J Environ Manage 270:110864. https://doi.org/10.1016/j.jenvman.2020.110864
23. Ketzer D, Weinberger N, Rösch C et al (2020) Land use conflicts between biomass and power production—citizens' participation in the technology development of Agrophotovoltaics. J Respons Innov 7:193–216. https://doi.org/10.1080/23299460.2019.1647085
24. Wüstenhagen R, Wolsink M, Bürer MJ (2007) Social acceptance of renewable energy innovation: an introduction to the concept. Energy Policy 35:2683–2691. https://doi.org/10.1016/j.enpol.2006.12.001
25. Fournis Y, Fortin M-J (2017) From social 'acceptance' to social 'acceptability' of wind energy projects: towards a territorial perspective. J Environ Planning Manage 60:1–21. https://doi.org/10.1080/09640568.2015.1133406
26. Busse M, Siebert R, Heitepriem N (2019) Acceptability of innovative biomass heating plants in a German case study—a contribution to cultural landscape management and local energy supply. Energy Sustain Soc 9:1–15. https://doi.org/10.1186/s13705-019-0215-2
27. SPD, Bündnis 90/Die Grünen, FDP (2021) Mehr Fortschritt wagen: Bündnis für Freiheit, Gerechtigkeit und Nachhaltigkeit. Koalitionsvertrag. https://www.bundesregierung.de/breg-de/service/gesetzesvorhaben/koalitionsvertrag-2021-1990800. Accessed 27 Sept 2022
28. Ministerium für Wirtschaft, Arbeit und Energie des Landes Brandenburg (2022) Energiestrategie 2040. https://mwae.brandenburg.de/media/bb1.a.3814.de/Energiestrategie2040.pdf. Accessed 20 Mar 2023
29. Umweltbundesamt (2022) Anpassung der Flächenkulisse für PV-Freiflächenanlagen im EEG vor dem Hintergrund erhöhter Zubauziele: Notwendigkeit und mögliche Umsetzungsoptionen. https://www.umweltbundesamt.de/sites/default/files/medien/479/publikationen/texte_76-2022_anpassung_der_flaechenkulisse_fuer_pv-freiflaechenanlagen_im_eeg_vor_dem_hintergrund_erhoehter_zubauziele.pdf. Accessed 27 Sep 2022
30. ZALF (2022) Energieerzeugung und Landwirtschaft kombinieren: Projekt „SynAgri-PV" bringt AgriPhotovoltaik raus aus der Nische. Pressemitteilung - 1.8.22. https://www.zalf.de/de/aktuelles/DokumenteMeldungen/Pressemitteilungen/2022_08_01_PM_AgriPhotovoltaik.pdf. Accessed 28 Sep 2022
31. Rada U (2022) Hühner unter Strom. https://taz.de/Ausbau-erneuerbarer-Energien/!5843109/. Accessed 28 Sep 2022
32. Bost M, Böther T, Hirschl B et al. (2012) Erneuerbare Energien Potenziale in Brandenburg 2030: Erschließbare technische Potenziale sowie Wertschöpfungs- und Beschäftigungseffekte—eine szenariobasierte Analyse
33. BUND Brandenburg (2020) BUND Brandenburg fordert Solardach-Pflicht – Ackerflächen werden für nachhaltige Landwirtschaft benötigt: Pressemitteilung. Landwirtschaft, Energiewende, Lebensräume. https://www.bund-brandenburg.de/service/presse/pressemitteilungen/news/bund-brandenburg-fordert-solardach-pflicht-ackerflaechen-werden-fuer-nachhaltige-landwirtschaft-benoetigt/. Accessed 25 Oct 2022
34. Land Brandenburg (2022) Photovoltaik und Solarthermie. https://mwae.brandenburg.de/de/photovoltaik-und-solarthermie/bb1.c.478389.de. Accessed 29 Sep 2022
35. Yin RK (2014) Case study research: design and methods, 5th edn. Sage, London
36. MQ P (2002) Qualitative research & evaluation methods, 3rd edn. Sage Publications, Los Angeles
37. Kuckartz U (2014) Qualitative text analysis: a guide to methods, practice & using software. SAGE Publications Ltd
38. Liebold R, Trinczek R (2009) Experteninterview. In: Kühl S, Strodtholz P, Taffertshofer A (eds) Handbuch Methoden der Organisationsforschung. VS Verlag für Sozialwissenschaften, Wiesbaden, pp 32–56
39. von der Dunk A, Grêt-Regamey A, Dalang T et al (2011) Defining a typology of peri-urban land-use conflicts—a case study from Switzerland. Landsc Urban Plan 101:149–156. https://doi.org/10.1016/j.landurbplan.2011.02.007
40. BUND (2022) Naturverträgliche Freiflächen-Solaranlagen für Strom und Wärme. https://www.bund.net/fileadmin/user_upload_bund/publikationen/bund/position/position_solaranlagen_freiflaechen.pdf. Accessed 14 Sep 2022

41. NABU (2022) Solarparks naturverträglich ausbauen: Anforderungen des NABU an naturverträgliche PhototovoltaikFreiflächenanlagen. https://www.nabu.de/imperia/md/content/nabude/energie/solarenergie/220330-nabu-positionspapier-solarenergie-solarparks-naturvertraeglicher-ausbau.pdf. Accessed 05 Nov 2022
42. Averbeck-Lietz S, Meyen M (eds) (2016) Handbuch nicht standardisierte Methoden in der Kommunikationswissenschaft. Springer Fachmedien Wiesbaden, Wiesbaden
43. Rädiker S, Kuckartz U (2019) Analyzing Qualitative Data with MAXQDA. Springer Fachmedien Wiesbaden, Wiesbaden
44. Sauer A, Luz F, Suda M et al. (2005) Steigerung der Akzeptanz von FFH-Gebieten: Abschlussbericht
45. BMEL (2019) 100er Boden—bestbewerteter Boden in Deutschland. https://www.bmel.de/DE/themen/landwirtschaft/pflanzenbau/bodenschutz/boden100er.html. Accessed 18 Mar 2022
46. Torma G, Aschemann-Witzel J (2023) Social acceptance of dual land use approaches: stakeholders' perceptions of the drivers and barriers confronting agrivoltaics diffusion. J Rural Stud 97:610–625. https://doi.org/10.1016/j.jrurstud.2023.01.014
47. Späth L (2018) Large-scale photovoltaics? Yes please, but not like this! Insights on different perspectives underlying the trade-off between land use and renewable electricity development. Energy Policy 122:429–437. https://doi.org/10.1016/j.enpol.2018.07.029

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