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RESEARCH ARTICLE

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Land use conflicts between biomass and power production – citizens' participation in the technology development of Agrophotovoltaics

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ABSTRACT

Despite the technical feasibility of renewable energy technologies and their contribution to climate-friendly power production public opposition can be a hurdle for new installations of renewable energy plants. This study assesses citizens' perceptions of the Agrophotovoltaics (APV) technology by applying the Responsible Research and Innovation (RRI) concept. APV combines biomass cultivation and solar power production at the same site in order to reduce land use conflict of food vs. energy production. In a workshop, citizens' perception on APV before building the first pilot plant was investigated to analyze relevant aspects for the innovation process and its framework at an early stage of the technology development process. This paper describes the findings from this workshop focusing on the impact of APV on landscape, biodiversity, economy, and on the requirements for regulatory framework.

Abbreviations: APV – Agrophotovoltaics; PV – photovoltaics; NIMBY – not in my backyard; RRI – Responsible Research and Innovation; SME – small and medium enterprises; BMBF – Bundesministerium für Bildung und Forschung (German Ministry of Education and Research); EEG – Erneuerbare Energien Gesetz (German Renewable Energy Sources Act); FONA – Forschung für nachhaltige Entwicklung (Research for a sustainable development).

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Introduction

In recent years, the use of biomass for energy production in Germany has increased due to changes in the regulatory framework and has led to increased competition between land uses (Rosillo-Calle 2012). The installation of ground-mounted photovoltaic (PV) for power production on arable land has reinforced this trend, leading to a trilemma of food, energy and environment (Tilman et al. 2009) which, with the expected price competitiveness of large-scale PV-plants (Reichelstein and Yorston 2013) through

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economically viable business models for ground-mounted PV, could increase the pressure on agricultural land even more. Agrophotovoltaics (APV), a combined system technology for the use of photosynthesis and PV at the same time and site (Obergfell et al. 2013; Schindele et al. 2014), offers a solution for this trilemma. This cultivation of agricultural plants or animal husbandry under high-mounted PV-cells (Goetzberger and Zastrow 1982) can be a win-win situation, as higher economic efficiency per hectare or animal welfare can be achieved (Beck et al. 2012). Despite these good omens, the construction of an APV can evoke a controversial debate in the public and raise questions about the acceptance of this technical solution. There is evidence that this might be the case: the implementation of renewable energy plants, e.g. wind turbines and ground-mounted PV, has met with some opposition from the public and has considerably delayed the energy transition in Germany. This observation is scientifically and publicly discussed as the NIMBY effect, the acronym for 'Not in my backyard' (e.g. Sütterlin and Siegrist 2017; Devine-Wright 2005, 2007, 2009). Reasons for citizens' critical attitude or even rejection often lie in the impact that these technologies have on the landscape. According to Smyth and Vanclay (2017), aesthetic changes of the landscape caused by energy projects have a great weight, since there is an emotional connection between people and places to provide leisure opportunities. These 'behavioral, affective and cognitive ties between individuals and/or groups and their socio-physical environment' are defined as 'place attachment' (Devine-Wright 2011). It can therefore be deduced that renewable energy projects which have an impact on the landscape must take the emotional ties and place-related symbolic meanings into account (ibid.). Therefore, in the end, the acceptance of renewable energies plays a crucial role for the German energy transition. In this situation, advanced 'better' science and technology integrating participatory approaches are pointed to as the way forward. Concepts such as Responsible Research and Innovation (RRI) seek to establish these links in order to consider social or ethical dimensions of technologies at an early stage of development and thus to achieve the integration of science and politics with society. To this end, research and innovation should be designed as a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view on the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society) (Von Schomberg 2011, 9).

Against this background, RRI requires early participation of citizens in the process of APV technology development and implementation in a deliberative manner.[1,2] With the help of deliberation, citizens' value orientations and norms with regard to APV and the acceptability of this technology can be identified and processed. The aim of citizens' involvement is to identify reasons and influencing factors for technology acceptance in a dialog and, if possible and required, to use this information to improve the technology and the framework conditions for implementation. This process can achieve both, technical and socio-technical argumentation aspects,[3] which can be considered as citizens' requirements and wishes towards different stakeholders. This includes, among others, politics as a framework and legislative institution. At best, these results are taken up by politics, project planners and technology developers, and incorporated into the research, innovation and regulation processes before introducing the technology.

The objective of the research presented in this paper is to identify and analyze the perceptions and expectations[4] of citizens towards Agrophotovoltaics in the deliberative format. The results contribute to the scientific debate on the relevance of early public participation following the RRI approach and the usage of the results produced, since RRI is regarded as an ideal process, but implementation of RRI has so far hardly been achieved. In this light, the first section describes the methodology of the deliberative step, which provides theoretical and practical information. In the second section of the article, the results of the citizens' participation are presented, outlining their specific expectations as well as concerns with regard to APV. Finally, these results are discussed and conclusions are drawn on overarching arguments and open questions considering the APV innovation process.

Methodology

Selection of participants for the citizens' workshop

The objective of recruiting participants for the citizens' workshop was to invite people that might get in touch with the APV pilot plant in their recreational life and are somehow 'affected'. With this framing, we wanted to avoid that the participation process[5] is only a theoretical exercise. The location intended for the pilot plant (cf. Figure 1) was visited and mapped to identify the population who might get 'in touch' with the APV-pilot plant, e.g. during bike rides and walks, or if the site is visible from their homes. Based

Figure 1. Map of the region 'Bodensee-Oberschwaben'. The star indicates the location of the pilot plant. Source: Modified after RVBO (2017).

on this selection criteria and the database of the Residents Registration Offices' registers[6] (Herdwangen-Schönach, Owingen, and Stockach), 2,176 adult citizens (aged between 18 and 80) were invited to declare their interest to participate in the citizens' workshop. 35 of the contacted persons registered for the workshop and 26 finally showed up. This corresponds to a response rate of 1–2%, which is in the range of comparable citizen participation formats (e.g. Fleischer and Quendt 2007; Fleischer et al. 2011). A reason that not more citizens registered could be that in the letter of invitation we expressly pointed out that the results of the workshop will have no impact on the process of granting the building permit for the pilot plant by the municipality. The group consisted of 23 male and 3 female participants with the expected age distribution: one was under 20 years, five between 40 and 49, nine between 50 and 59, six between 60 and 69 (three of them above 65), and four between 70 and 76 years[7] and one person who did not indicate the age.

The three phases of the citizens' workshop

At the workshop, the participants were first briefly introduced to the APV technology and the research approach before starting with the three workshop phases. In the first brainstorming phase, four parallel discussion rounds were conducted to identify the participants' issues regarding APV. This phase allowed for a discussion of individual and consensual issues, which are of concern to the participants, rather than topics set by the researchers in advance. In phase two, the main four topics of interest were selected to be discussed in the third phase with a World Café approach to get a broad overview and understanding of the participants' general perceptions and opinions on APV on a rather detailed individual and intra-individual level. In the following, the different phases will be described in more detail.

Phases 1 and 2: identification of citizens' main issues

Group discussions were used for brainstorming at four parallel tables. In a lose discussion set-up, all participants were asked to present their initial thoughts about the opportunities and challenges related to APV, guaranteeing a greater level of detail through their interaction. This approach was chosen in order to leave the choice of topics for further discussion to the citizens themselves and not to produce restrictions through a prior decision by the project team and thus a bias. In addition, a much more constructive and creative discussion was expected when citizens could bring in 'their' own issues. One researcher per table facilitated the participants' discussions by collecting important aspects from all participants. Chances and risks of APV were discussed at a very general level, rather than talking about the pilot plant.[8] At the end of the group discussions, all issues were gathered (which had been written on small cards by the participants) and classified into eight categories by the workshop organizers (cf. Table 1). It has to be mentioned that some notes were ambiguous and might have been allocated to more than one category. The participants were then asked to rank their main topics by assigning a maximum of three points, each (one point per topic only).

Phase 3: the World Café

For the discussion of APV-related issues, the World Café approach was chosen as it enables participants to discuss in a relatively open set-up that allows grasping more

Table 1. Overview of categorized results from the group discussions.

Thematic clusters	Arguments from the participants	Points
APV and the Energiewende	• Pros and cons of APV, comparison with other renewable energies, open questions, concerns	14
APV and the landscape	What is desirable concerning size, height, removal, visual cover, accessibility?	14
APV and the profiteers	Who wins, who loses? • Participation schemes • Effects on employment • Cost-benefit ratio	12
APV and the politics	• Information policy • Subsidies policy (e.g. EEG) • Legal framework	11
APV and the potentials	Which areas and where to install it? • Arable land, grassland, speciality crops • Distance to settlements Questions and concerns: • Which criteria must be considered technically, economically, and socially? • Why APV and not PV on sealed areas? • Site criteria • How to evaluate high and low quality soils? • How can APV be designed in order to make it acceptable? • How can undesirable development be avoided? • Chances for agriculture, assessment of experiences	7
APV and the technical requirements	Which criteria must be fulfilled? • Made in Germany, worth the money; safe; recyclable; aesthetics Questions and concerns: • Stability, snow, machine size, mounting height, dust and hail, irrigation and water management, power storage, PV only useful with power storage, producing power vs. changing behavior	5
APV and 'Zeitgeist' and sustainability	How do I view APV? How do I feel about it? Is APV sustainable? Questions and concerns: • Improved environmental sustainability • Disposal and recycling • Impacts on nature (e.g. flight of birds, dazzling effects) • Electro smog, a risk for plants and animals? • Electric radiation, how do plants and animals react? • Impacts on food quality?	4
APV in Germany	• Potential for Germany • Export hit?	1

Note: The four topics with the highest rankings were chosen for the World Café discussions. The arguments were not structured or formatted, but taken as noted by the participants.

interactive approaches than methods that are organized around a central focus of attention. Nanz and Fritsche (2012) describe the World Café approach as small group discussions with a table host (either external or one of the participants) that run for around 20–30 min, after which participants switch tables and mix the groups. By these changing constellations, new processes of framing ideas are generated, experienced discussants encounter new discussion partners, and increasing levels of detail can be achieved which often lead to proposals for solutions (Nanz and Fritsche 2012) and surprising ideas through an 'interactive fertilization of ideas' (Steyaert, Lisoir, and Nentwich 2006). Consequently, each participant attends one discussion round on each topic. In order to 'provide continuity of ideas' (Jorgenson and Steier 2013), discussions from the previous group will be briefly presented to the new group by the table host. The new group is then able to expand on details or develop existing ideas further, but might also critically review existing ideas. Thus, large groups can be handled to collect inputs, exchange knowledge, stimulate innovative thinking and explore opportunities of action (Steyaert, Lisoir, and Nentwich 2006).

In contrast to other methods, the World Café allows participants to discuss without being guided through the discussion, namely without moderator or interviewer, and has thus proven to be very successful in participatory approaches (e.g. MacFarlane et al. 2017). In usual World Café set-ups, one participant stays at each table to serve as a host for the next group and presents the key findings and ideas of the last group discussion (Steyaert, Lisoir, and Nentwich 2006; Holman, Devane, and Cady 2007). We decided that a scientist will be the host to enable all participants to take part in all discussion rounds, rather than staying at one table. Knowing about the risk of having a scientist as host, the role was restricted to a facilitator's role (no thematic input) making sure that the discussions stuck to the topic, with a minimal degree of disruption and influence. Participants taking over the discussion or continuously repeating the same arguments were restrained by the host, while silent ones were encouraged to share their opinions. In contrast to the usual set-up (cf. Steyaert, Lisoir, and Nentwich 2006; Nanz and Fritsche 2012), no joint plenum discussion was conducted after the four rounds, as the purpose of the workshop was to grasp the individual participants' perceptions, rather than finding a joint opinion.

Qualitative content analysis

All discussions from the workshop were captured by audio recording and note taking. After the workshop, all recordings were transcribed and anonymized. The analysis of the transcripts followed the qualitative content analysis method (Mayring 2000; Mayring and Fenzl 2014). Each participant was assigned an abbreviation code to respect their privacy while enabling a follow-up of ideas during the discussions in the transcript. This way, it was possible to follow discussion streams and identify statements that build on each other. Categories were inductively chosen to analyze all aspects. As category construction needs particular attention (cf. Mayring 2000, 2014), we intensively discussed and updated the categories as a team in order to find the best substantiation. For the coding of the material, we used 'open coding' following a line by line procedure (Mayring 2014). The results were discussed in order to jointly depict the main findings. The categories for qualitative content analysis are presented in the results section (see chapter 3). Each category has several subcategories, each representing a topic that the listed statements referred to. An anchor citation for each category and sub-category provides a typical example for the character of the category (Mayring 2014), providing additional insight in how the arguments were raised compared to, e.g. a pure collection of topics, keyword analyses, or purely paraphrasing the content. Furthermore, a short summary was given for each category, a list of (shortened) key citations, limiting the citations to key statements, as well as the list of full citations. This way, the anchor citation gives an indication of what topics the category comprises while listing the arguments allows for allocating weight to arguments by knowing which and how many participants made statements on this topic.

Results

An overview of the thematic clusters developed at the first phase of the citizens' workshop is given in Table 1. In the second phase (cf. points in Table 1), a total of 68 points (out of 78 possible) were assigned by the participants. Through this ranking procedure, these topics were regarded as of main issues to be selected for phase 3:

(1) APV and the energy transition (14 points);
(2) APV and the landscape (14 points):
(3) APV and the profiteers (12 points);
(4) APV and the politics (11 points).

Beyond these four topics, other issues were debated in phase 3 of the citizens' workshop, too. Therefore, the results for three more topics are presented here:

(5) APV and agriculture;
(6) APV and environmental sustainability;
(7) APV and the regulatory framework.

An overview of the key results of these seven categories is given in Table 2. In this section, for each of these seven categories a discussion summary complemented by some (direct) quotes of the participants is given.

APV and the energy transition

For the participants, there has been no doubt that the energy transition is important to combat climate change and that power production from coal and gas, as well as nuclear plants must be replaced by renewable energies. Most of them believed that the energy transition requires the use of all renewable energies (wind, solar, water and biomass). However, it was emphasized by one participant that the 'largest energy source, which is still unused, is the saving of energy' (p. 6, line 204) and that 'steering of the demand along with the supply' is crucial for the efficient use of renewable energy (p. 8, line 321 f).

The APV technology was compared to other renewable energy technologies available on the market. The comparison of APV and wind power was not so clear, as wind power has been discussed controversially among participants. Some perceived a single wind power plant 'as a vitalization of nature', being 'less incisive than APV', which was considered as a 'technical box' (p. 13, line 535 ff), while others criticize the height of wind power plants.

Compared to biogas, APV was rated as significantly more advantageous as biogas production was assessed as an unsustainable and undesirable option, because it is linked to large areas of high-growing corn plants leading to the 'destruction of soils' (p. 37, line

Table 2. Overview of key findings and recommendations of the citizens' workshop.

	Comparison to other renewable energies	APV and the landscape	Agricultural cultivation	Environmental Sustainability	Planning framework for APV	APV and the politics	Who are the profiteers and losers
Main arguments	Use roofs and industrial sites for PV first, then APV	Fear of uncontrolled growth	Agricultural cultivation must be mandatory	Production of the mounting system, recycling and disposal of PV must be considered.	Limitations in size and density for a municipality/ region.	EU-regulations to be further specified into regional/ local specifications.	Local recreation and tourism might be disturbed by APV
	Decentralized production: bring product and consumption together at one site with power storage.	Integration in the landscape scenery important to avoid industrial artefacts.	Quality and quantity of yields must be analysed for a holistic assessment.	Standardized modules allowing for replacement and repowering.	Good governance and well-defined permission procedure required.	German Renewable Energy Sources Act (EEG) as good example of a foresighted policy.	Operation mode by cooperatives or municipalities as best option.
	Avoid un-planned developments (cf. biogas).	Better integration expected for flat areas than for hilly areas	Reduced heat stress in summer expected.	Unspecific possible impact on flora and fauna mentioned.	Involvement of citizens and municipal councils required.	Certain share of self-supply with energy for a region.	Farmers can be winners (if APV is economically viable) or losers (if farming land leases would increase)
	Higher acceptance for APV than for ground-mounted PV, biogas, and wind power.	No 'roofed Allgäu', avoid large sprawls over several square kilometers.	Shade tolerance and eventually altered/ reduced water supply below panels must be investigated.	Include life cycle assessment in the assessment of the technology.	No APV on the best and most productive soils, minimum distance to settlements.	Criteria for locations should be taken by municipal councils as they have the best knowledge.	Risk of overtaking of arable land by industrial investors.

1541) and 'high traffic loads' (p.37, line 1562). The 'uncontrolled cultivation of maize' is considered as the consequence of an unsustainable energy policy.

When comparing APV with ground mounted PV, the opinions among participants were also different: many did not see much difference, while others assumed a higher impact of APV on the landscape due to the mounting system. Several persons expected only minor impacts from APV as they regarded it as a sustainable and ethically justifiable combination of food and power production. One participant commented that people have to tolerate impacts from renewable energies if installed in a way that 'humans and nature can live with them in a good way' (p. 8, line 316 ff.). As explicitly stated by one participant, APV as well as PV in general needs to be combined with power storage to have the maximum benefit and thus to relativize the intervention in the landscape by a high power yield.

In general, most participants assessed APV favorably compared to biogas and ground mounted PV, since it allows for the double use of agricultural land for food and power production and at the same time has a similar impact on the landscape than open space PV. Compared to PV on the roof, though, APV was rated significantly worse. A strong claim was stated by two participants that PV should first be installed on the (still) still available roofs and industrial areas, e.g. parking lots, before covering agricultural fields with APV (or ground mounted PV). This repeated statement became the joint opinion of all participants until the end of the workshop. Based on experience with PV on private roofs or community-based installations, some participants argued that PV modules on roofs would also be cheaper than APV due to the existing transformer and feed-in infrastructure. As a counter-argument, two participants argued that even if all suitable roofs would be covered with PV, only around half of the electricity demand could be covered (cf. p. 32, line 1329 ff.). However, since around 90% of the roof area is in private hands, it would be difficult to force PV-installation on roofs as a political target (cf. p. 23, line 968 ff.). Thus, it could be inevitable to install PV on other sites as well.

The participants insisted that a final judgment can only be made after the market introduction of APV, since, at a large scale, this technology could have severe impacts on landscape and agriculture. An unregulated and inappropriate installation of APV plants may look like a 'roofing of the landscape'. Besides concerns were raised that food production below the modules will be neglected. In that respect, the participants referred to maize cultivation to feed the biogas plants which increased land use competition, and altered the landscape and its aesthetic as well as recreational value.

APV and the landscape

Since the workshop took place before the APV pilot plant was built, the participants had only a sketch and a small wooden-model to imagine how the plant might look like. Nevertheless, this topic was discussed intensively. Participants were concerned that APV could be installed in 'untouched' agricultural areas detached from any infrastructure. This would change cultural landscape to one characterized by technical elements and could cause serious public concerns end even rejection, since people 'want to see nature, nothing technical' during walks and bike rides (cf. p. 149, line 6355). Two participants perceived APV as 'free of charm' (cf. p. 80, line 3383 ff.), whereas they described wind turbines and high-voltage power lines as 'some kind of artwork' in the landscape (cf. p. 13, line 533, 535).

Some participants pointed out that both, size and location of the APV plant are crucial for their appearance since the plant looks different from an uphill than a downhill perspective. They expected a better integration into landscape, if APV plants are not installed in mountainous or hilly regions, but preferably in plain regions. However, large-scale application over flat arable areas or grassland and the idea of a 'roofed Allgäu[9]' evoked the participants' concerns (cf. p. 105, line 4467 ff.).

Many participants regarded the entire region of Lake Constance as a beautiful landscape and holiday destination where APV should not be installed at all. Here, places of 'idyllic landscape' exist where installing APV would be 'absurd' (cf. p. 101, line 4294 ff.). They argued that APV installations might negatively affect the region's attractiveness for recreation and could lead to a decline in tourism which is an important business creating jobs and income in that region. Tourists from urban areas might not be interested in the region any longer, as 'experiencing steal and industry' would be the same as staying at home (cf. p. 84, line 3607 ff.). Municipalities might face negative effects as changes in the landscape could lead to a decline in tourism (cf. p. 151, line 6463 ff).

Some participants compared APV to existing hail protection nettings in the region and in particular in South Tyrol, which is famous for apple production and tourism. There, the nets are used on a large-scale sprawling over several square kilometers, which strongly influences the visual impression of the landscape. In contrary to hail protection nettings that are flexible and are only opened during the apple growing season, some participants perceived APV as even worse since it is not only temporarily visible, but permanent and has an appearance like the roof of a greenhouse. Only one participant argued that APV over apple orchards would be less incisive since the visual impression of hail nettings or APV would be similar.[10]

In the discussion about suitable locations with respect to the distance to power consumers, some participants preferred to place them away from settlements to avoid impacts on the vista from peoples home. Placing them at the edge of forests or on glades would reduce their visibility. Others suggested to keep APV away from cultural landscapes and to place them close to urban areas where infrastructure and consumers are located. Hiding APV plants behind visual protections, e.g. hedges, was not regarded as suitable, because it might have a negative impact on agricultural production, e.g. by shading effects.

APV and agriculture

All participants agreed that agricultural cultivation under the PV modules must be kept mandatory and should be monitored. Consequently, not only the yields, but also possible changes in food quality (e.g. size of potatoes) shall be analyzed (cf. p. 77, line 3218 f). Some participants pointed out that APV could help to reduce plants' heat and water stress in hot and dry summers by its shading effect (cf. p. 77, line 3244 ff). On the other side, they expect an altered distribution of rainfall since more water will reach the soil between the modules than below the modules. Even more, one participant assumed that in the same way, hailstones would be unequally spread, causing a delay or hindrance of the plants' growth between the modules where they would accumulate.

The participants discussed the impacts on soil quality and field management between the pillars as well as the suitability of different crops to be grown below the PV modules.

Some participants were arguing that it could be difficult to manage diversified crop rotations due to varying plant tolerances towards shading and reduced water supply by rain below the panels. On the other hand, one participant pointed out that irrigation or pesticides spraying systems could be attached to the APV pillars and supplied with electricity produced by the modules.

One participant questioned whether APV would be in line with the production of high-quality food according to the regulations of the German organic cultivation association Demeter.[11] Another participant noted that APV could be used above animal grazing areas similar to ground mounted PV where sheep are grazing to prevent plant growth. However, one participant was concerned about animal husbandry below APV since this could change the quality of food, e.g. lead to 'contaminated' milk by electro smog emitted by the APV plant. Another participant tried to explain that APV produces direct current electricity which will not lead to any electro smog.

APV and environmental sustainability

For the participants, environmental sustainability was not a major issue, probably because the main objective of APV is to contribute to a more sustainable energy supply and by this to mitigate climate change. However, some participants discussed about the production impacts regarding life cycle thinking, especially the production of the mounting system and the recycling or disposal of the PV modules after their lifetime. They proposed to investigate the entire supply chain and ecological life cycle of the plant (cf. p. 72, line 3062), expecting a steel rather than an aluminum construction, as power production from APV would never be able to compensate for the energy needed for the aluminum production (cf. p. 72, line 3064 ff). Several participants criticized the industry for not including Life Cycle Assessment (LCA) in the design of their technologies, processes and products. One participant questioned the replacement of PV modules, as technical equipment would often be available for a limited time (around ten years) only. An experienced PV user replied that standardized modules had been available for the last 20 years allowing for replacement and repowering. He also mentioned that recycling of the modules is already established.

Beyond the LCA issue, only concerns about biodiversity were raised. Some participants assumed that flora and fauna would be affected by APV, but no specific examples were given. One participant pointed out that any negative impact on nature has to be avoided because this could pose a heavy threat to APV (cf. p. 130, line 5575 ff.).

APV and the regulatory framework

All participants agreed that it is crucial to set up a coherent and mandatory regulatory framework at different scales (local, regional, national, and EU level) to ensure that APV plants are only installed where they should be according to the sustainability criteria defined by society before. By this framework, it should be avoided that APV will 'get out of control', meaning that APV plants could be installed everywhere, like biogas plants, or only used for profit maximization by power production while neglecting or suppressing food production. Participants agreed that a privileged building permission for farmers, as it has been the case for biogas plants, should be prevented for APV to avoid uncontrolled construction of APV plants.

In general, defining criteria for the selection of appropriate APV sites and developing the regulatory framework was regarded as a tricky and complex task. Thus, 'intellectual weirdos' should be engaged in the process, as decision-making requires more than just rational thinking (p. 130, line 5550 ff.). All participants agreed that agricultural cultivation below APV modules should be mandatory (cf. p. 133, line 5676). Farmers should continue to produce food rather than to maximize power production even if more profit can be made by power production compared to food production while needing at the same time less work (cf. p. 130, line 5563 ff). Besides, some participants regarded soil quality as a main criteria for the selection of APV sites. According to them, APV should not be built on the 'best soils', but only on land with low soil quality, such as on the Swabian Alb. However, since these soils are stony and below one meter of depth, they are not regarded as suitable for a stable mounting system necessary for APV.

Another more subjective, but not less important criterion pointed out by some participants, was the landscape and that only those sites should be selected for APV 'where it is not beautiful' (cf. p. 96, line 4056 f). Besides, some participants believed that slopes should be avoided as APV plants sited there would be visible from far away, whereas flat areas were considered to be more acceptable. They suggested to define a minimum distance to settlements, as such is the case for, e.g. wind power. These limits should be defined at a regional, rather than at national or European level. Other participants were in favor of visual protection measures, such as trees or hedges, surrounding the APV plant as long as they do not hinder or restrict farmers' field management (cf. 3.2).

Moreover, some participants stated that only single small plants shall be granted building permits and a concentration of several plants in one and the same region should be avoided, since this is regarded as inacceptable (cf. p. 111, line 4696 ff). One participant recommended to allow only 'a limit of 10% of the municipalities' areas for APV (cf. p. 131, line 5568). Others called for a limitation on areas belonging to farms, preferably on land owned by the farmers and not on leased areas, which should be prohibited (cf. p. 112, line 4735 f) to prevent that 'foreign' investors from outside the region or even the country will take over the regional APV market. Besides, several participants claimed that the operator of the APV plant and the owner of the agricultural land should be identical to avoid conflicts between food and power production as an increasing number of PV modules (for optimization of the power output) would decrease biomass yields. However, privileging farmers was also identified as a possible threat, as they have special rights for privileged building projects on arable land.[12] Besides, some participants regarded APV plants operated by non-farmers as advantageous, as they might offer participatory investment by local citizens in case the farmers cannot raise enough capital to invest in APV. If local farmers or municipalities produce electricity with APV to satisfy their demand, a higher acceptability was expected.

Defining suitable framework conditions for APV is regarded as essential by all participants. Different opinions on possible subsidies and funding schemes were discussed: Some argued that APV should be granted a feed-in tariff, whereas others feared an over-funding leading to an uncontrolled expansion. One participant regarded subsidies for renewable energies as a general challenge. Some participants suggested not to provide more funding for APV than for ground mounted PV,[13] and less than for PV on roofs or industrial areas, as they should be prioritized over APV (cf. 3.1).

Although a sophisticated national regulatory framework specified at the regional levels, e.g. by land-use planning, was regarded as important by all participants to reduce possible drawbacks from APV on landscape and agriculture, respectively, some participants warned that regulations should not be too strict as they could then prevent the implementation of APV[14] at all: one participant suggested that municipalities should define maximum and minimum target values for renewable power production in general and APV, respectively. However, this might introduce a risk of local favoritism or even corruption (cf. p. 129, line 5538 ff.): granting one farmer a permission to build an APV plant, while denying it to another, would get municipalities into trouble (cf. p. 131, line 5636 ff.).

APV and politics

According to many participants, political decision-makers play a crucial role in implementing and regulating APV. One participant stated that agricultural and energy issues in general are mainly regulated at European and national levels (cf. p. 106, line 4483), but that decisions are also needed at regional level. However, trust in politicians has been regarded as an important issue, as some politicians could see APV as technology for local prestige projects ('Look, what fantastic thing I have built here') (cf. p. 123, line 5211 ff). Some participants questioned whether citizens could really trust politicians to solve controversial issues, while others criticized that 'everyone complains about politics, but at the same time calls for their decision' (cf. p. 123, line 5282). The knowledge of politicians is regarded as 'problematic, as politicians often know less [about perspectives] than the participants' (cf. p. 121, line 5123 ff). Others pointed out the 'German renewable energy act (EEG) is a positive example for a foresighted policy' (cf. p. 121, line 5129 ff). The governance structures were controversially discussed, though (cf. 3.1). Some participants demanded an energy concept for the region.[15] Others were suspicious of politicians ('When they meet, they don't know more than we do') and questioned whether these would want an energy concept (cf. p. 119, line 5053 f). At the same time, the EEG was damned for cultivating huge areas of energy maize for biogas plants. One participant suggested to establish an authority that ensures a certain share of own energy production for a region and which then decides for the best technology based on region-specific criteria.

APV and the profiteers

The participants debated about who would benefit or have disadvantages from APV plants at the local and regional levels. Some did not expect a significant impact on the local economy, assuming that installation and maintenance would be performed by specialized companies throughout Germany or even the European Union, rather than by regional retailers. Moreover, once the APV plant is installed, not much work will remain as PV is a low-maintenance technology.

Most participants believed that technology developers and material suppliers will be the economic 'winners', while the local population would experience the negative impacts of APV. They expected that local residents, walkers, hikers, and tourists would have to live with the drawbacks from 'less beautiful' and 'industrialized landscapes and scenery', in case APV plants would be installed (cf. p. 149, line 6344 ff). Most of the participants argued that the majority of residents would have to live with the altered landscape for a long time, whereas there would be only a few profiteers. This might even reduce the number of tourists and recreational day visitors, with possible socio-economic drawbacks for the region. Tourists are interested in 'holidays in a cultural landscape shaped by food producing farms', and not in a landscape and farms 'spoiled with solar panels' (p. 150, line 6421 ff). One participant recommended to develop a regional sustainability concept to balance the interests of potential APV investors and local population to avoid unequal distribution of benefits and burdens among the population. In this context, some participants voted to implement and operate APV by cooperatives, which are already an 'established mode of operation' (p. 146, line 6237 ff) in the renewable energy sector. This would 'lead to an increased level of acceptance, as one could identify with the own plant' (p. 146, line 6247 ff) and it could be an option to maximize the regional output through financial participation schemes (cf. p. 146, line 6210 ff). Some participants favored cooperative operations, as technical hurdles are not that high and thus municipalities could be possible operators (p. 146, line 6247 ff). Cooperative models and financial participation schemes would help to foster the citizens' willingness to accept APV plants in their neighborhoods. A few participants even stated this as a precondition for approving APV plants. In this operation mode, all infrastructures must be set up by the farmers and citizens, including handling all disadvantages. For this vision, one participant addressed the difficulty to 'reconcile three farmers', which is regarded to be almost impossible (p. 147, line 6260).

The farmers were seen as either winners or losers in the discussion: they might win, if the cost–benefit ratio is favorable, but lose if they cannot invest in APV while investors drive up lease prices for farm land. The participants argued that the energy industry has enough available funds to push small farmers out of the market as it has already happened during the last decades. Contrary to this, others considered the large energy suppliers as losers of the energy transition, as most of the renewable energy capacity is owned by private investors. Furthermore, they might try to take over large areas without really ensuring that the food production below the PV modules is performed properly.

Discussion

The deliberation dimension of RRI for APV comprises the participation of interested citizens followed by the analysis of their perceptions, values and their line of arguments. By referring back to value orientation, this accounts for the RRI-approach which can serve as a general approach for assessing new technologies. The findings confirm that arguments on impacts brought up by the participants serve for considering implications in dissemination and use of new products in the prospective reflection of the innovation path (cf. Grunwald 2017). The identified socio-economic aspects raised by the citizens prove that risks of the technology are to a large extent systemic risks, which can only be regarded in their social interplay with society (Hellström 2003). In this context, the results of the workshop show that deeper insight into citizens' perception of new technologies such as APV can be gained through integrating citizens into a research project. This way, the study contributes to the existing literature on citizens' opinions about renewable energy infrastructure and the social acceptance of the energy transition, which has become an increasingly important topic over the past decade (Devine-Wright et al. 2017).

Even though renewable energy supply at the regional scale is considered as important by all workshop participants, the results confirm other studies about citizens' varying levels of acceptance of renewable energy technologies (e.g. Wüstenhagen, Wolsink, and Bürer 2007; Musall and Kuik 2011; Stigka, Paravantis, and Mihalakakou 2014), depending on whether they refer to an overall acceptance (abstract perspective) or the actual acceptance of a new infrastructure in their neighborhood (concrete perspective) (Sütterlin and Siegrist 2017). Among participants, solar power had the highest and biogas the lowest acceptance level among renewable energy technologies. This is related to the fact that most of the participants were familiar with renewable energies and had a good level of knowledge about the energy transition. Moreover, some participants reported about their own experience with private or cooperative owned PV plants and proposed to restrict the expansion of biogas plants due to perceived negative local impacts.

Even though representative studies (e.g. AEE 2015) show high acceptance levels for renewable energies in general and for PV in particular, a general (public) acceptance of renewable energies cannot be directly translated into local acceptance (Sütterlin and Siegrist 2017). Thus, the authors recommend to provide a holistic picture of related drawbacks and trade-offs to citizens to allow for an informed decision making. Since the workshop took place before the APV plant was built, we could not provide such a picture based on facts. Therefore, the participants only appraised the APV concept as suitable to reduce land use competition between energy and food production. For a final judgement, they requested detailed information about the technology, especially concerning economic viability, life cycle assessment (incl. recycling and disposal), and food quality, which shows that a systems perspective has been developed by the participants that goes well beyond NIMBY only (cf. Devine-Wright 2005).

APV and the environment (landscape and biodiversity)

The results indicate that, for the workshop participants, implementing APV in a sustainable manner at a commercial scale means to respect local and regional characteristics of the landscape and interests linked to them, such as recreation and tourism, since APV is regarded as a huge and massive construction which could reduce the landscape's attractiveness. They indicated that the planned APV site is usually considered to be an idyllic place of high value for recreation, associated with personal memories (local identity). As a consequence, the citizens recommended to use other sites 'where it is not (so) beautiful', which can be regarded as a typical NIMY reaction. This finding is in contrast to a study on windfarms in South-West Scotland, which could not confirm reduced tourism attractiveness or find any other evidence for a net impact on tourism (e.g. Warren and McFadyen 2010).

Other studies indicate that local acceptance of renewable energies is also dependent on their impact on the environment (e.g. Bergmann, Colombo, and Hanley 2008; Musall and Kuik 2011). For example, in discussions on wind power, the endangerment of birds and bird conservation is a crucial topic (Eichhorn and Drechsler 2010). In our study, we did not find clear evidence that this is also the case for APV, as only a few vague statements were made on possible impacts on biodiversity and ecosystems. These statements expect negative impacts by, e.g. dazzling effects for birds as well as positive impacts, since APV does not, in contrast to ground mounted PV, require a fence which would restrict the movement of animals (Turney and Fthenakis 2011). Microclimate changes under APV

(Turney and Fthenakis 2011) are expected to be similar to ground mounted PV (shadow induced by the PV modules), and seen as both disadvantage and advantage depending on the species of flora and fauna.

APV and the business model

According to the results of the workshop, the APV plants should be owned and operated preferably by local farmers and energy cooperatives. This statement is consistent with the evidence drawn from literature studies on wind power that local participation and/or ownership has a positive influence on public acceptance (Schreuer and Weismeier-Sammer 2010; Warren and McFadyen 2010). The number of local energy cooperatives investing in solar parks has risen in recent years (Oteman, Wiering, and Helderman 2014; Hoppe et al. 2015), whereas 60% of the energy cooperatives are operating PV roof-mounted and 15% ground mounted PV-systems. By 2014, almost 1,000 cooperatives existed in Germany with around 130,000 private members (Klagge et al. 2016). However, the role of local participation in APV was questioned by some participants, as they rather expect financially sound (foreign) companies to invest in large APV plants and an EU-wide competition for APV installation and maintenance as well as only little maintenance work. This assumption goes along with the fact that institutional and utility companies are recently investing in large ground mounted PV plants (Schreuer and Weismeier-Sammer 2010), whereas in the past, in particular small private owners invested in PV (e.g. from 2007 to 2009).

Community-based APV operation, which provides institutional space for local facilitation and innovation (Oteman, Wiering, and Helderman 2014), was favored by the participants, too, since they respect the 'cultural-cognitive and normative institutional features' of communities (Wirth 2014) and aim to improve regional benefits and share the profits. These findings are in line with other studies on renewable energies (Kalkbrenner and Roosen 2016). Our findings show that higher acceptance levels can be expected if the municipality plays a key role in building and operating an APV plant, since local councils will commit themselves to find the best possible site and adaptation to local conditions as well as in steering power production and demand to match the local supply with the local demand. Community ownership is associated with positive attitudes to renewable energy installations. This was shown in surveys of residents exhibiting 'a strong sense of pride in and connection with 'their' windfarm' (Warren and McFadyen 2010). Community initiatives are characterized by their participants being active in the planning, decision making, and exploitation of projects for producing their own renewable energy (Oteman, Wiering, and Helderman 2014). Examples from other regions (e.g. the state of Brandenburg in Germany) show a wide range of actors involved in the 'organizational landscape of energy provision', with very place-specific energy cooperatives or model communities from local residents and farmers (Moss, Becker, and Naumann 2014).

Despite all these benefits, community involvement cannot be seen as an easy and complete solution to increase acceptability of wind or other renewable energy installations (Warren and McFadyen 2010). Most importantly, energy transition projects must take social aspects into account and involve citizens as investors and volunteers based on trust and social norms (Kalkbrenner and Roosen 2016). At the same time, economic risks are described for distributed ownership of (wind) energy projects: a large number of people involved can be a risk for the economic viability, as there are higher transaction costs and reduced economies of scale (Schreuer and Weismeier-Sammer 2010). Furthermore, single projects cannot distribute risks as efficiently as several projects, where risks and benefits would be pooled, since it is difficult to assess the economics of renewable energies as there is quite often contradictory and inconsistent information available (Zoellner, Schweizer-Ries, and Wemheuer 2008). Although technology developers argue that APV systems can be competitive with small roof PV systems (Innovation 4E 2017), due to lack of data, the participants were not able to make estimations on the economic viability. Still, they believed that it will be necessary to provide a specific subsidy scheme for APV. Regardless of the business model, APV should be competitive in the future without subsidies and have positive effects on the national and local economy.

APV and the regulation

In the light of our results, local citizens should participate at an early stage in the planning process to consider regional conditions and include practical knowledge from 'local experts', which is consistent with the findings of Hübner and Pohl (2015). According to their recommendation, policy makers should provide a regulation framework, which can be adapted by each municipality according to local conditions (see above). Despite the call for political regulation to avoid a free market development, there is also skepticism or even mistrust about politicians' work.

The debate about public participation in developing the regulatory framework is caused by features that come along with the energy transition: since renewable energy plants (onshore) are smaller than coal-fired plants, more local decisions have to be taken. Also, the 'relative visual impact' (per MWh of output) tends to be higher due to lower energy densities (Wüstenhagen, Wolsink, and Bürer 2007). At the same time, new regulations (e.g. 10 H minimum distance for wind power in Bavaria) restrict the planning significantly (Tyroller 2017) and are therefore viewed with scepticism by investors. This was also criticized in the media and renewable energy communities (e.g. BWE 2017; Steinert 2015). This indicates that general regulations and the process of citizens' participation need to be adapted to consider not only local conditions, but also integrate local citizens in the regulatory framework for the permission of APV plants.

APV and participation

Public participation is of increasing importance for policy makers when implementing renewable energy technologies to mitigate climate change (Devine-Wright 2011). Despite our findings that participants are supporting the objectives of the energy transition and like the APV concept of combining food and power production, they are concerned about drawbacks for the cultural landscape and its beauty. There is another trade-off between short-term costs of the incumbent technology APV (and the demand for subsidies to make them competitive against ground-mounted PV) and the long-term benefits of the double harvest concept and the production of renewable power. However, the pros and cons for a renewable energy installation can be evaluated and weighted differently over time, resulting after all in a more favorable public perception since citizens are getting used to the energy plant, as to any other technical construction or building, in their neighborhood and environment (Wilson and Dyke 2016). This development of fear was described by Warren and McFadyen (2010) in the case study of windfarms as follows: After an initial phase of positive responses while no nearby schemes are planned, the responses turn into negative ones once a scheme is in planning nearby. After gaining personal experience, they returned to positive responses. In contrast, Hübner and Pohl (2015) raised some doubts about the NIMBY hypothesis for local wind power plants. They described consistent attitudes towards wind power in general and towards local installations. They stated that critique from residents is caused by serious worries, which need to be handled accordingly, as these worries will not disappear over time, but can trigger major opposition against a technology after market introduction. Our findings support this hypothesis requiring innovation processes to consider societal needs and concerns from the beginning in order to increase public acceptability. While political decision based on a democratic process might not be enough to reach that goal, participation can provide a holistic picture of the technology (Schweizer et al. 2016). In this context, local participation is crucial for creating 'a space for new operating models' (Schweizer et al. 2016). Even if there is no guarantee, there is at least a justified 'cautious optimism' for a sustainable development of framework conditions. Hübner and Pohl (2016) concluded from large-scale infrastructure projects that participation processes are not automatically leading to a problem-free planning procedure or even acceptance, but conflicts and public debates can be limited significantly. We believe that public participation should not be limited to large-scale plants, but rather start at an early stage of technology development and implementation. This way, there is still room for technology developers and decision-makers in politics, administration, and business to benefit from early participation and to improve their work to achieve a higher public acceptability.

According to this hypothesis, we have communicated the results of our citizens' workshop to technology developers and business companies, decision-makers in politics, administration, and other stakeholders. The findings on technical issues were reflected by our technical project partners and this reflection was provided to the participants of the workshop to give them a feedback on their suggestions and concerns. Moreover, a second citizens' and a stakeholder workshop were organized to further discuss the findings presented in this paper. The final results have been discussed within the inter- and transdisciplinary project consortium with partners from science and practice as well as with the advisory board. The results will be tackled in the upcoming innovation concept about APV (to be published). The innovation concept will comprise policy recommendations how to further develop APV plants and how to implement and operate them sustainably by addressing the needs and concerns expressed by the workshop participants.

Conclusions

This paper provides the worldwide first insight into citizens' perceptions of the benefits and risks of a APV plant enabling the double harvest of food and power to reduce land use conflicts as well as general and specific recommendations where to site and how to implement and operate such a plant in a sustainable manner. Although our findings disclosed an overall positive public attitude giving priority over ground mounted PV, it has to be noted that an APV market launch could become difficult if there would still be significant roof and industrial areas available for PV installations. Besides, environmental impacts of APV should be evaluated, preferably via Life Cycle Assessment, to complete public information on APV technology.

Our findings show that it is crucial that APV systems are integrated into the scenery at best to avoid negative impacts on recreation and tourism. Therefore, preferably sites which are considered as 'not beautiful' shall be identified, even though the definitions about beautiful landscape may differ among local residents. From a systemic point of view, there is evidence that APV should be integrated appropriately into (existing) infrastructures and supply chains, if available, and coupled with power storage for an efficient and preferably high-value local use of power produced by the APV plant. Since citizens aim to support that local farmers can live on food and power production, there is at the same time a lack of trust that farmers will continue food production once the APV plant is installed. Therefore, there was a general agreement among citizens that good agricultural cultivation must be mandatory to avoid a one-sided optimization towards solar power and so-called 'pseudo-agriculture'.

Our findings indicate that the success of renewable technologies depends to a large extent on a proper regulatory framework and local acceptance, rather than mere technical aspects. Public participation at an early stage of technology development and pilot scale, however, is not sufficient for robust and transferable statements on the acceptability of commercial large-scale APV plants. Therefore, public participation before implementing the first commercial APV plant is required to validate our findings. Here, the process of framing the APV technology by appropriate financial incentives and regulations taking into account citizens' concerns on landscape aesthetics, recreation, and tourism as well as food production, plays a crucial role in order to gain societal benefits from the double harvest technology, which requires a broad public acceptance. For a sustainable planning process, decisions on plant locations should be taken at municipal level to best consider local characteristics. Highest acceptance levels can be expected for community owned plants through participation processes, both from a planning and economic viewpoint. A well-developed governance strategy must address operators and investment structures while respecting region-specific criteria for size and concentration, but at the same time avoid over-regulation to keep planning and implementation of APV plants possible. When planning APV plants, the process should be transparent and respect the needs of farmers and neighbors likewise to allow for a responsible implementation of this innovation. The participants emphasized the important roles of municipal councils and local communities for renewable energies. By involving citizens in the technology development process, the quality of decisions increases smoothing the path for a more sustainable technology development, as it includes a user perspective from the beginning.

From a scientific perspective, the workshop concept comprising three phases has proven to be appropriate and successful in order to investigate citizens' opinions on APV as an example for a new technology that has not been realized yet. Their valuable feedback has been reflected by technology developers and decision-makers, which is in line with the RRI concept to assess technologies already at a development stage and include a user perspective early in the process. This feeds into recommendations on how to develop and frame the technology for high acceptance levels and a successful market introduction. Due to time and budget constraints, only a few of these aspects could be taken up and implemented during the course of the project.

Notes

1. The RRI concept includes four dimensions, the anticipative, the reflexive, the responsive and the deliberative dimension (see e.g. Lindner et al. 2016). In this article, however, we will limit ourselves to the deliberative dimension and focus on presenting the results of this research and innovation.
2. The deliberative dimension of RRI involves the open provision of visions, goals, questions and dilemmas in broadly based deliberative processes, which provide both an interested public and various stakeholder with dialogue forums and space for engagement and debate. This ensures the articulation and exchange of a wide range of perspectives and enables the adaptation or even reorientation of questions and the identification of potential controversies.
3. A distinction is made between technical aspects, which could be solved by adapting and modifying the technical components of the assistive system, and socio-technical aspects, which can be dealt with primarily by measures other than the specific technical solution. It is clear to the authors that the distinction made is not sharp, since strictly speaking technical and non-technical aspects cannot be decoupled from each other.
4. It should be noted, however, that the authors had to make a selection due to the variety of topics.
5. Representativeness is initially given by the random sample described later, which was only limited by the selection "affected by" the pilot plant. Following an explorative approach it was not the primary goal to picture the opinion of a given population, but to identify acceptance criteria for APV. But, besides this, further research is necessary to quantify the importance of the identified criteria.
6. According to §32 Meldegesetz Baden-Württemberg (registration law), this data can be used for research of public interest. All data has been handled according to data protection laws and was only used for this research project.
7. We deliberately do not include educational attainment, marital status, etc. in the evaluation and assessment of citizens' statements as we did not want to derive any statements related to this information. Of course, these can also have very exciting results, but that was not the focus of the study presented.
8. It is important to mention that the participants were reminded in the introduction to not discuss about the pilot plant specifically, but to think visionary about the future use of the APV technology installed on agricultural areas in Germany after its market introduction. In this discussion, of course, the pilot plant served as a role model. Furthermore, it was clarified that the scientific participation approach is completely independent from any participation step in the planning process for the pilot plant.
9. Geographic subregion of Upper Swabia dominated by grassland and known as a holiday region.
10. In this context, a few participants complained that the local population did not have any vote about hail netting, but had to accept it and its impact on the landscape when it was introduced at Lake Constance.
11. The pilot plant is installed on farmland which is operated under special organic farming conditions called Demeter (cf. www.demeter.de).
12. Under the German building law, farms located outside villages do not fall within the scope of a qualified development plan. Since agricultural area is used for natural land use and public recreation, in principle, this area should be kept free of any development, i.e. construction projects are initially not permitted. Exceptions are listed in § 35 of the Building Code (BauGB). Among other things, agricultural enterprises are granted a building right under certain conditions – this is referred to as a privileged building project.
13. The existing EEG funding regulation for ground mounted PV has been criticized by some participants as this fosters their installation along traffic routes, whereas difficult to cultivate and thus abandoned agricultural areas or slopes cannot be used.
14. Some participants pointed out that in the state of Bavaria strong regulations to protect the beauty of nature prevented any wind power planning.
15. There is an existing energy and climate protection concept from 2012: http://www.rvbo.de/Konzepte/Energie--und-Klimaschutzkonzept

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