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Research article

Driving and restraining forces for the implementation of the Agrophotovoltaics system technology – A system dynamics analysis

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ABSTRACT

The innovative Agrophotovoltaics (APV) system technology combines agricultural biomass and solar power production on the same site and aims at reducing the conflict between food and power production. Unrelated to this benefit, this technology may impact the landscape negatively and could thus be subject to public opposition and/or restraining frameworks. The presented study offers a System Dynamics (SD) approach, through Causal Loop Diagrams (CLDs) models, based on the results of citizen workshops, literature research, and expert discussions on the technology. A comprehensive analysis of the driving and restraining forces for the implementation of APV-technology and expected or potential impacts reveals influential factors. Hence, this SD approach identifies bottlenecks and conflicting objectives in the technology implementation that need to be further addressed. A key finding is that successful APV-projects would require stakeholder involvement to achieve greater local acceptance. When it comes to production on agricultural land, APV-systems may drive the land use efficiency to up to 186 percent when the PV-panels serve for protection against heat stress. On the other hand, altered precipitation patterns and impacts on agricultural cultivation and, especially, the landscape caused by the technical system, may restrain the application of APV. Finally, system design factors and operator modes are amongst the criteria that may influence the local acceptance in society, farmers' motivation for APV and economic factors for the market launch of APV.

1. Introduction

The use or availability of fertile arable land in Europe is limited and threatened by nature conservation processes, urbanization, infrastructure and industrial needs, climate change, but also demographic changes that may lead to increasing land demand in the future (Kroll and Haase, 2010). In recent years, conflicts have increasingly arisen between housing, infrastructure, biomass production and food (EEA, 2011). Adding to the 'food vs. fuel'-dilemma (e.g. Baffes and Haniotis, 2010), various subsidy and funding programs (e.g. Renewable Energy Sources Act (EEG), agricultural subsidies) and political strategies (e.g. bioeconomy strategies, etc.) lead to direct and indirect land use changes (iLUC) (e.g. Wiegmann et al., 2008). In particular, agricultural land is increasingly claimed for food and energy, particularly power production (Harvey and Pilgrim, 2011). Besides biogas, also ground-mounted Photovoltaic (PV) structures on agricultural land were receiving a feed-in tariff (FIT) in Germany. A monitoring study (ARGE PV-Monitoring, 2007) found that 70% of the 41 monitored PV-systems were installed on areas previously used for agriculture under the EEG. Whereas in 2010 75% of the additional ground-mounted PV area was installed on arable land, the ban of PV on arable land adopted in July 2010 excluded PV until 2016 (Kelm et al., 2019). A resolution passed by the German Bundestag in 2016 enables the federal states to declare specific green areas and arable areas for PV-systems (BMWi, 2016b). Since 2010, 3174 ha of traffic area and 15,640 ha of conversion areas were covered by PV, while the use of unprivileged areas (arable land) accounted for only 104 ha until 2017. During the last years, the installed area peaked with 6440 ha in 2012, dropping to only

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Abbreviations: APV, Agrophotovoltaics; PV, Photovoltaic; NIMBY, not in my backyard; RRI, Responsible Research and Innovation; SME, Small and Medium Sized Enterprises; EEG, Renewable Energy Sources Act Germany; FIT, Feed-in tariff within the EEG; CLD, Causal Loop Diagram.

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730 ha in 2017. Out of the 27,000 ha of PV systems installed, around one quarter occupied arable land, while the majority of 62% was installed on conversion areas (Kelm et al., 2019). New land-use systems are required to sustainably increase the efficiency of the agricultural land use. The Agrophotovoltaic (APV) system technology aims at reducing the so called food vs. power dilemma by combining food production and power generation on one site (Schindele et al., 2014). This way, it offers farmers two separate sources of income, which may also raise income security. At the same time, local recreation and tourism, important sectors for many rural regions, are closely linked to maintaining traditional landscapes. As APV may impact the character of the landscape significantly, social acceptance needs to be assessed ahead of policy-making or the installation of such systems (Rösch, 2016; Trommsdorff, 2016).

Any changes in the set-up will, however, impact the agricultural and/or PV-system. To analyze structural dynamics and feedbacks, this paper uses System Dynamics (SD) for developing an APV-system perspective that allows assessing these complex interactions. The links and relations between the identified arguments are mapped to Causal Loop Diagrams (CLDs), which allow for a qualitative understanding of the system's dynamics. CLDs visualize key findings for policy recommendations to define a sustainable framework for APV-systems. This way, the present study aims at providing a comprehensive understanding of the dynamics rather than a modeling study predicting accurate results. Knowledge of the dynamics should permit better planning and collaboration between sectors, enabling comprehensive and sustainable technology development and implementation. Against this background, we intend to identify bottlenecks in optimization processes.

2. Background

In the course of the German energy transition ("Energiewende"), the EEG introduced a FIT for biogas and ground-mounted PV-systems for power production (among other technologies). In 2017, renewable energies accounted for 15.6% of gross final energy consumption in Germany (BMWi, 2018), by 2035 it is planned to be 55–60% (BMWi, 2016a). Renewable resources are produced on more than 14% (2.4 million ha) of the total agricultural area and 20% of arable land (FNR, 2019). Improved spatial planning is required to balance differing needs and demands as well as attendant stakeholder conflicts.

Simultaneously, erosion must be limited to maintain soil fertility and reduce freshwater eutrophication (Withers et al., 2014). Dietary guidelines are advertising ecological cultivation and plant-based nutrition, which requires larger cultivation areas (Mason and Lang, 2017). As PV-systems have taken fertile arable land out of agricultural production in the past, receiving building permits for ground-mounted PV has become more complicated and subsidies declined in several countries (Marcheggiani et al., 2013). In 2010, 75% of added capacity from PV was installed on arable land. After July 2010, ground-mounted PV systems in Germany were only covered by the FIT if installed within 110 m of traffic routes (e.g. motorways or railways). This ended the boom of ground-mounted PV systems (Rösch, 2016) and PV on arable land was absent until 2017 (Kelm et al., 2019). As solar power technologies will become competitive within years now, 80% of PV plants in the IRENA database to be commissioned in 2020 should be independent from financial assistance of e.g. FIT or tendering (IRENA, 2019).

Besides technical, economic, ecological, and legal aspects, social and societal arguments of renewable energies have become a central strand of public discussion. Landscape aesthetics is becoming an urgent issue as energy production takes place in nature rather than industrial areas, but also in areas with significant cultural landscapes and touristic values. Especially wind power and biogas have led to 'Not in my Backyard' (NIMBY)-movements, which, when aggregated, may have the influence to restrict decentralized energy supply (Staniszewska, 2014). Visual impacts were cited as an argument in participation processes for the impact of PV-systems on tourism and local recreation (cf. Ketzer et al., 2019; Warren and McFadyen, 2010; Musall and Kuik, 2011; Bergmann et al., 2008). Stakeholder and citizen workshops ought to be organized to include public opinion in the process (Schweizer et al., 2016), as some citizens express serious concerns about renewable energy projects (Hübner and Pohl, 2015). Such approaches potentially improve problem solving, take local needs and interests into account and in the best case, jointly develop strategies for a decentralized energy system without 'sacrificing' important local concerns. Despite positive examples of successful processes and citizen-owned plants, a more general understanding of the acceptance criteria for more sustainable planning and site identification is necessary though.

The APV system technology (cf. Fig. 1) enables farmers to continue cultivating their land and simultaneously produce renewable energy (Goetzberger and Zastrow, 1982). With a specific set-up, it is designed to increase hectare output for higher area efficiencies (Beck et al., 2012b) with PV and biomass production or livestock farming. Shading effects may lead to an improved availability of water for biomass production (Marrou et al., 2013a), especially in dry periods (Schindele et al., 2014; Dupraz et al., 2011; Weselek et al., 2019b). An overview of APV approaches, also called 'Agrivoltaic, 'Solar Sharing', or 'Agro PV', can be found in Weselek et al. (2019b). Besides targeting higher area efficiencies, APV-systems shall foster rural development in the agricultural and energy sectors by stimulating local entrepreneurship by farmers, municipalities/communities, and SMEs. In Japan, higher profits per hectare by applying APV-systems are seen as a strategy to encourage young people to stay in rural areas (Movellan, 2013).

3. Objectives

There is a need for a more comprehensive understanding of technical and economic aspects, agricultural issues around APV-systems as well as of factors affecting societal acceptance. From an implementation perspective, APV-systems are challenging not only in an engineering sense, as they interact with agriculture, local economy and stakeholders, societal perceptions of sustainability and landscapes. While the technical system behavior is influenced by highly dynamic external factors, the combination with agriculture causes a strong internal feedback. Implemented on a larger scale and dependent on allocation, future APV installations may affect the visual and/or functional landscape entailing risks for cascading effects on other sectors (e.g. tourism and local recreation) and potential negative impacts (e.g. reduced number of tourists and reduced local economy). Bringing this knowledge into a system's representation with the help of SD is essential to identify driving and restricting factors, but also trade-offs, unexpected effects and to optimize APV-systems. Understanding the underlying mechanisms of the

Fig. 1. APV-pilot plant at the Heggelbach farm community (Hofgemeinschaft Heggelbach), Lake Constanze region in Southern Germany. Copyright: Hofgemeinschaft Heggelbach (2017).

system in the wider sense enables an estimation of outcomes. For the identification of driving forces for APV-systems, the SD-approach highlights the driving factors named by the stakeholders involved. At the same time, the dynamic representation allows to visualize the impact of restraining forces that might impede a successful implementation of APV on arable land. Hence, the achieved knowledge builds the basis for identifying trends, prospects, and recommendations. It also identifies areas of uncertainty that require more knowledge or clarification, the need for policy development and regulation, and constraining factors seen by different stakeholders for defining regulations.

4. Methods

Systems Analysis and model-based understanding of systems deal with the questions of the understanding of linked causal and feedback mechanisms (Grunwald, 2010; Haraldsson, 2000; Sterman, 2000). For this study, a SD approach is used to gain an understanding of the techno-economic-ecological structure and dynamics of the agricultural and energy system as well as their interplay as an APV-system based on causalities and feedback. Feedback within the system can be analyzed by using the provided, unambiguous language of the CLDs (Sterman, 2000; Schlyter et al., 2012; Haraldsson, 2000; Sverdrup et al., 2010). Independent variables may affect the outcome of dependent variables in the same direction, described by an arrow with a plus (+) on the arrowhead, or with a minus (−) for the opposite direction. Ambiguous (or undefined) connections are marked with a '?'. A balanced loop is indicated by 'B', a reinforcing loop by 'R'. External factors serve as drivers for the system.

In this way, not only the connection between two single factors, but entire argumentation chains and especially feedback-loops can be recognized. The example in Fig. 2 shows how factors are indirectly affected by a causal and loop structure. External drivers, such as *advertisement* in this example, provide external input to the system. In doing so, it is possible to represent policies, for example. The interactions in the systems build up the dynamics of the entire system (Sterman, 2001).

Understanding systems structure and mechanisms allows using them to identify critical components and processes, trends and outlooks as well as leverage points in the system (Meadows, 1999). CLDs make the technology understandable as an interrelated system, identify causes and effects, indicate the drivers of the dynamics, and characterize the patterns. In contrast to the conventional approach of bringing the whole range of affected stakeholders together in several consecutive group modeling sessions, an approach with a mix of workshops and knowledge derived from literature studies was employed to develop a conceptual model of the interaction between the APV-system and the landscape. Group model building (e.g. Vennix, 1996; Maani and Cavana, 2000; Sterman, 2000) has been successfully used to analyze complex land-use and value conflicts, e.g. in the Swedish mountain areas, and to identify means for a better acceptance of exploitation through improved local (landscape) resource management (Sverdrup et al., 2010; Schlyter et al., 2012; Stjernquist et al. 2012). The described concept of synthesizing CLDs based on various qualitative approaches should similarly involve the full breadth of ideas and support stakeholders to better understand the dynamics within the APV-sector in terms of benefits, losses, potential trade-offs and mitigation measures. Revealing the dynamics enables more informed decision-making in planning and cooperation, in support of an improved sustainable technology development and implementation. Feedbacks within a system become visible and pitfalls can be identified to better understand a system as a whole to drive intended while avoiding non-desired effects. Hence, 'what-if' simulations can be conducted to map how changing parameters impact the system and the system feedbacks (cf. Ziemann et al., 2016).

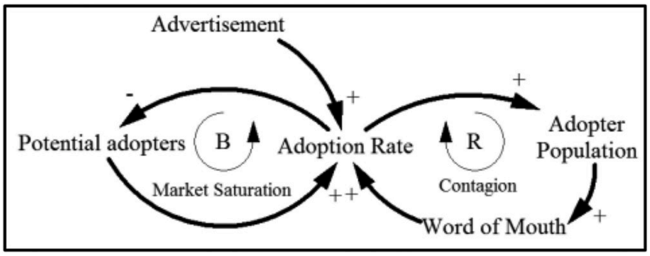

Fig. 2. Example of a causal loop diagram (CLD). Modified according to Sterman (2001).

4.1. Input information and assumptions for the qualitative model

The systems structure is based on literature studies and discussions on APV within the APV-RESOLA-project. As part of the project's innovation group,[1] continuous meetings have built up a broad familiarity with the disciplines required for the assessment of APV. Based on the findings from the 1st citizen workshop prior to the pilot plant installation (referred to as 'WS1'), the 2nd workshop after one year of operation (referred to as 'WS2'), and the stakeholder workshop as final event (referred to as 'WS3'), the arguments raised in the workshops are brought into a CLD representation (cf. Table 1). A list of assumptions and sources is given in the supplementary material to this paper. Some connections are marked with a question mark ('?') accounting for unclear statements, contrasting views, or behavior of the system that need clarification.

4.1.1. Main assumptions relating to the agricultural system

Radiation and *precipitation* are external local climate conditions which drive the agricultural production system and influence *water availability* and *cultivation conditions*. *Shading effects* by the *mounted PV-system* reduce the *radiation* (i.e. the Photosynthetically Active Radiation (PAR)) reaching the ground by about 30% (Innovation 4E 2017). The *heterogeneity of the radiation* is determined by the height of the modules (which in fact depends on the *clearance height*). It increases with proximity to the ground (Dupraz et al., 2011). A southeast or southwest orientation of the modules enables a more homogeneous radiation distribution for the plants (without persistent shade), while producing slightly less power (Beck et al., 2012a). *Sheltering effects* of the modules could reduce *water availability*, whereas the modules also redirect the water. This leads to an *uneven distribution of water* (less water below the panels) and to *puddles and rills* on the ground (increasing the availability on some spots of the cropland), which could amplify *erosion* (Dupraz et al., 2011). Besides, *hedges/visual protection* around the installation may additionally impair cultivation. In the innovation group and WS3, the function of the *stripes* taken *out of production* by the mounting structure were evaluated as beneficial for *biodiversity* and for reducing *erosion*. Representatives of environmental protection NGO and regional planning authorities emphasized the large area demand of ground-mounted PV systems and the importance of maintaining refuges for fauna. The central driver of the agricultural system, the *biomass yield per hectare*, could not be assigned a clear trend from *shading effects*: lower yields under APV were found for the first study year of the pilot plant (cf. Weselek et al., 2019a) whereas the second year (a very dry summer) resulted in increased yields (cf. Fraunhofer Institute for Solar Energy Systems ISE, 2019).

4.1.2. Main assumptions for the technical system

The assumptions for the PV-system follow physical rules and are in most parts similar to the ground mounted PV-systems. Power production

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[1] The innovation group in the APV-RESOLA project consisted of a transdisciplinary team from research, agriculture, industry, with regular exchange to public administration and an external advisory-board. http://www.agrophotovoltaik.de/english/project-partners/.

Table 1
Overview of input information from the participatory approach for the qualitative model.

Approach	Own assumptions based on findings	WS1: 1st citizens' workshop	WS2: 2nd citizens' workshop	WS3: Stakeholder workshop	Literature research
Structure of data	Authors' assumptions based on the work in the innovation group, literature findings etc.	Single statements	Single statements	Single statements, motivated statements.	Scientific publications and online-material
Type of participants		Citizens from the municipalities around the pilot plant	Citizens who participated in the 1st citizens' workshop	Stakeholders from tourism, environmental protection, regional energy agency, Regional Citizens' Energy Cooperative, regional council, Environmental Ministry, industry representative, farmers' association, Citizens' representative, Municipality mayor.	

is directly linked to radiation. The static requirements for the mounting system are defined by the *number of modules installed per hectare* (weight-dependent), the mounting height (*clearance height*) and site-specific criteria. The *massiveness of the structure* follows the surrounding conditions (e.g. *slope of areas*, *wind speed*, *snow and ice risk*, etc.). The *distance between the pillars* of the mounting system leads to more or less *beneficial cultivation conditions* for large agricultural machinery and the area lost for production.

4.1.3. Main assumptions for the acceptance level of APV

The acceptance level of the APV technology mostly relates to the findings of WS1 – WS3. In WS1, the general precondition for APV was clearly defined and then confirmed in WS2 and WS3: the potential of roof PV and sealed area PV (e.g. industrial areas, parking lots, streets etc.), but also noise-insulating walls, must be exploited before installing any APV-plants. This claim of the citizens (WS 1&2) was reinforced by the environmental protection NGO representative. Based on WS1, a *cooperative operation* of APV may raise the *acceptance level for APV*, while investors should not be eligible for investments in APV. C*onsideration of local practical knowledge*, which is driven by *local knowledge* and *citizen participation*, shall be mandatory to develop *local criteria* for a *locally legitimatized planning framework* to reduce uncontrolled growth. This has been a prerequisite for both, citizens and the environmental protection representative. Defining *local criteria* incorporates an *increased risk for too detailed criteria* though, which might make planning impossible (cf. frameworks for wind power in Bavaria, e.g. Dehmer, 2016). The *number of installations* adversely affects the *acceptance level for APV*, as most citizens and stakeholders (WS1 – WS3) prefer to restrict the *area occupied by APV*. It was controversially discussed in WS1, however, how the *distance to houses* impacts the landscape. Hence, *landscape integrity*, driven by *landscape impact*, *visibility* and *forest surrounding*, was central to the discussion in WS2. *Tourism revenues* were highlighted as key drivers for *regional economy* and *employment*, while the farmers' organization's representative also highlighted the relevance of tourism for farmers. *Farmers' interest in APV* would increase with *economic viability*, while low maintenance of the PV technology and few specialized companies installing such plants (WS 1 - WS3) would limit the benefits for the *regional economy* or *employment.*

5. Results

The translation of qualitative statements into a SD-structure reveals the strong impact of changes within the system. A series of CLDs are presented to provide further insights into conflicts of interest between different land users for food and energy, the land efficiency, public perception, and economic dynamics of APV. The pure (mere) number of influential drivers gives an indication that there is no universal APV-system. Important adjusting screws, which lead to a varying outcome if changed, are described in the text to highlight the dynamic interaction of the driving forces.

5.1. A systems approach on APV

Agricultural land and its use for biomass and/or power production is altered by policies, strategies and (external) international *oil price* developments (see Fig. 3). In simple terms, the citizens involved believe that *energy efficiency*, a key objective of the Energiewende, is a very important driver for reducing land use conflicts, as it directly affects the primary *energy demand* and thus the need for more *renewable energy capacity*. Further, the CLD shows how PV-systems installed on agricultural land directly interfere with the *area needed for food and fodder production.*

On closer examination, a very complex and dynamic APV-system was identified. The agricultural production and the technical system of the APV-system with its interconnections are presented in Fig. 4. External variables can be found on the left side, while the outcomes are rather on

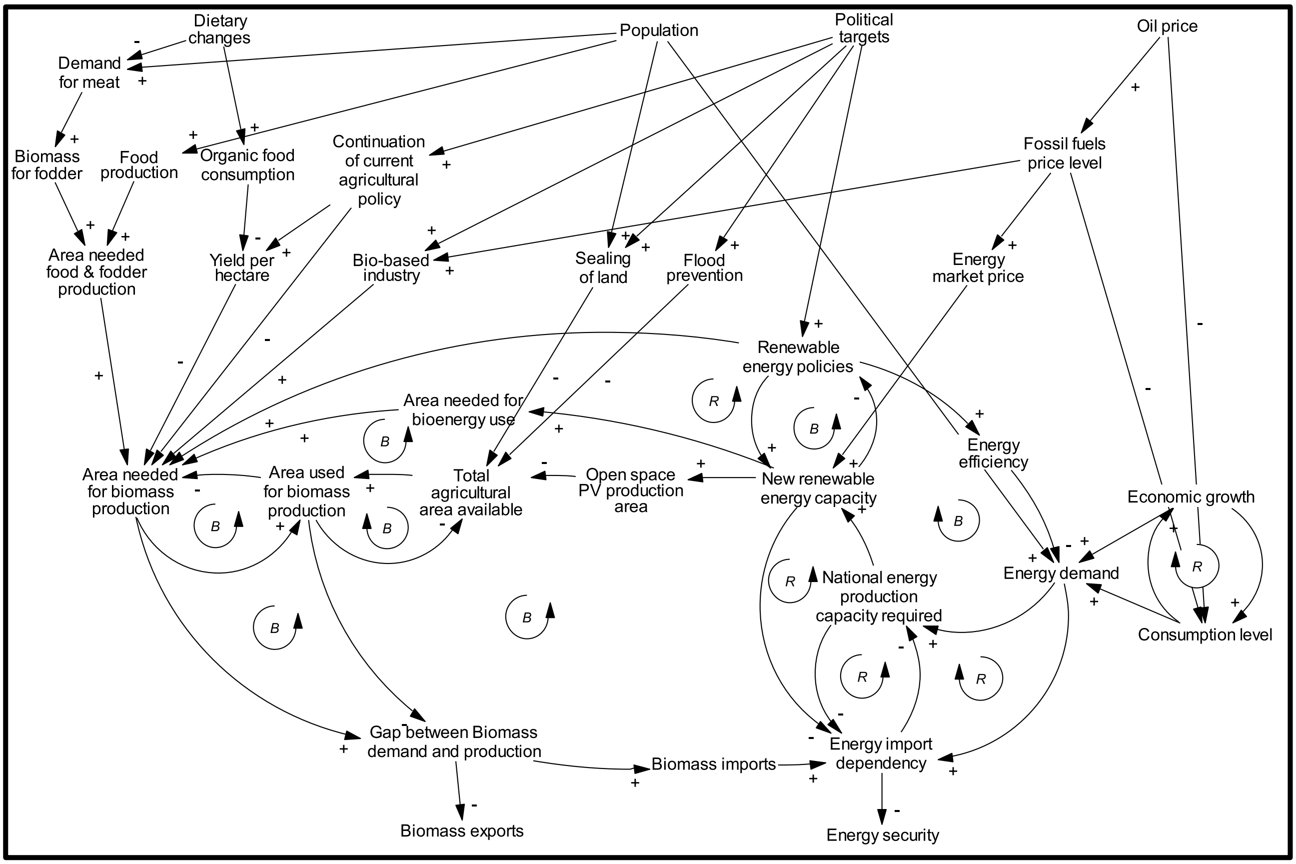

Fig. 3. Interlinkages between biomass and PV-production systems.

the right. The main factors for agriculture are site-specific climate-variables. Technical factors to the left create the dynamic feedbacks within the system. The relation between these factors (e.g. *wind speed*, *snow and ice hazard* at the site), but also factors determining the structure of the mounting system (e.g. *PV-modules/ha, distance between pillars*, *clearance height*) directly depend on the APV set-up. Whereas a lower *clearance height* tends to reduce the *landscape impact*, it may increase the *variability of radiation on ground level* causing more *shading effects.*

Finally, these changes impact the biomass yield both, directly and indirectly, through more or less *beneficial cultivation conditions*. The *area occupied by the structure* is lost for biomass-production, while it might proof beneficial for biodiversity. The APV-system must be carefully designed to avoid *dropping runoff from modules* and *shelter effects, which influences* the *cultivation conditions* again.

For a regional context (see Fig. 5), several main drivers were mentioned. First, having *exploited roof* and built up (paved or hardened) areas with roof or ground mounted *PV* are a prerequisite for accepting APV at all. People are concerned that fertile agricultural soils will be defined as *area suitable for APV*-systems (while the potential of roofs etc. remain underutilized), which is not appreciated. In citizen workshops, participants proposed to rather use poor soils to minimize the loss of biomass yields. For the *landscape impact* as well as the *landscape integrity*, PV-structures must be as filigree as possible. While the *size of the plants* increases the *economic viability* of APV, the participants of all workshops clearly demanded a size-limit as a decisive factor driving the *acceptance level for APV*. While the citizens' representative in the stakeholder workshop saw the planning and approval phase as crucial, the energy cooperative saw no room for discussion, as there is an urgent need for renewable energies. On the municipality level, the stakeholder argued that trust in the technology will be improved by research with *citizen participation.* Research would thus be beneficial for a proper *framework*. In the planning process, citizens should be involved to achieve a higher acceptance level.

Besides the mere *size of the plants*, the *acceptance level for APV* is driven by several direct and indirect factors. *Farmers' interest in APV* is a multi-layered criterion combining economic and agricultural factors (such as *profitability APV*, *cultivation conditions*, etc.), with societal and legal aspects (e.g. *local knowledge)*. While the *attractiveness for investors to invest in APV* (for e.g. co-investment) would make APV more attractive to farmers, it would be a restricting factor for public acceptance and should be avoided by building a *locally legitimate planning framework*. In this context, the ministry representative argued that large farmers would not be interested in APV and citizens and stakeholders would prefer only farmers or *cooperative operation*. For a *locally legitimate planning framework*, the municipalities should define development plans to account for local knowledge and site criteria. Such a framework would directly and indirectly drive the *number of installations*, which in turn lowers the public *acceptance level for APV* with a delay. Citizens and tourism representatives would reject *an extensive area occupied by APV* as this reduces the *attractiveness for tourism* and *local recreation*. This opinion was underpinned by the experience made with hail protection netting in the Lake Constanze area, which tourists regard negatively (cf. WS3). On the other hand, some citizens and stakeholders argued that both, renewable energy tourism and local production of food (which needs protection against hail), could turn out to be subjects of tourism marketing.

5.2. *Identification of drivers and potential target conflicts*

While the economic system (see Fig. 6) is characterized by a majority of internal balancing loops (B4–B9) for the PV-system, the nature of the loops for the agricultural system highly depends on the impact of shading. The PV-system strongly impacts the output of the agricultural production, whereas the PV-system is merely externally driven. Namely, more shading effects occur if the number of PV-modules increases or if

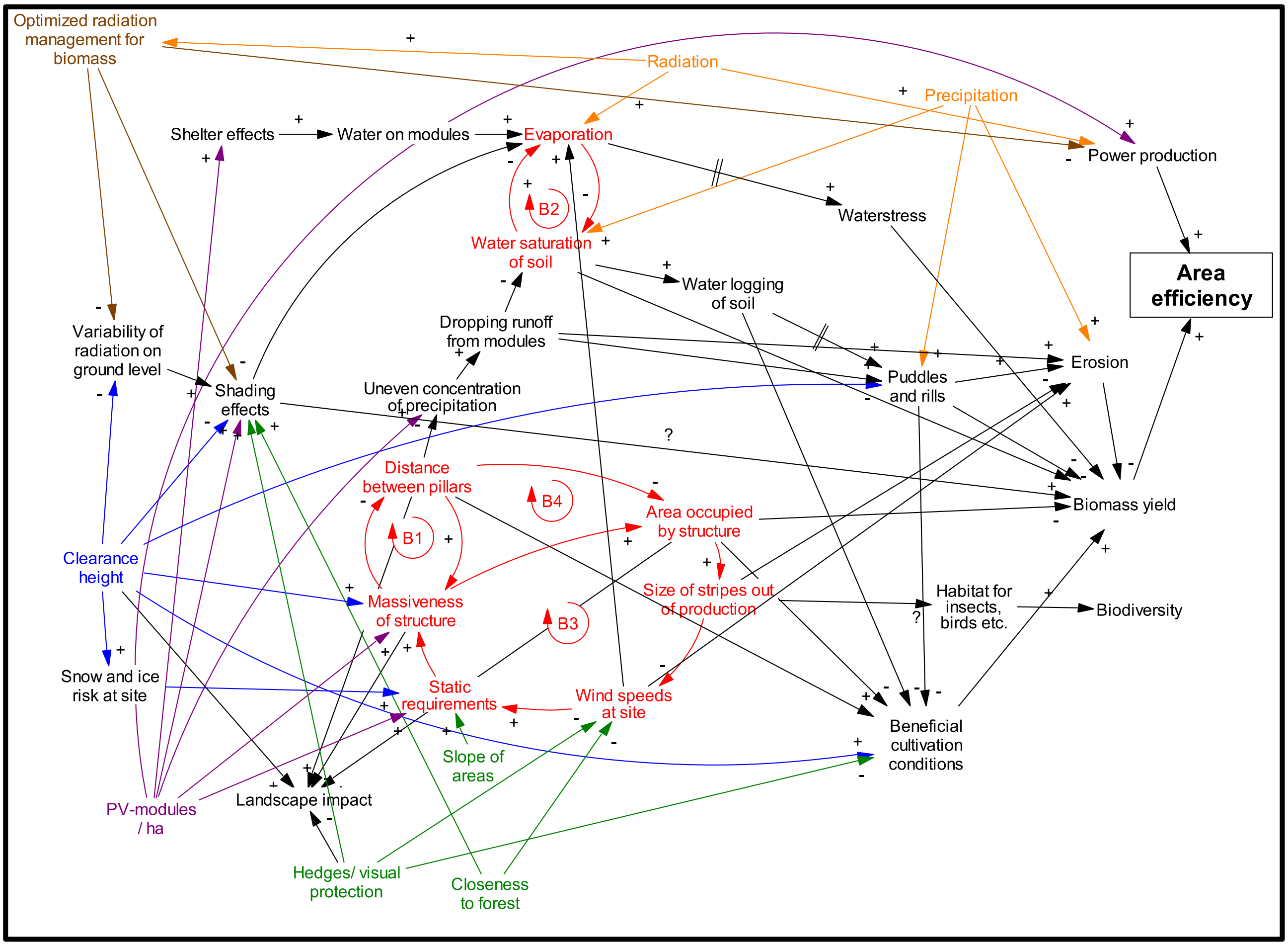

Fig. 4. Key interlinked factors affecting APV efficiency. Driving and restraining factors for the public acceptance of APV.

the modules are better aligned. At the same time, however, it is expected that an optimization of the PV set-up will result in a more economical APV-system as higher outputs are generated. Cost reductions are possible by reducing the *clearance height* and thus the *static requirements*, which have a direct negative impact on the *heterogeneity of the ground radiation* and the *cultivation conditions* though. This can result in a *reduced biomass* yield which affects the overall objective of the APV-system. At the same time, there seems to be a delay in *maturing time* caused by the shading of the plants, which could lead to *off-season production,* which in turn could benefit farmers. Whereas differences in *biomass price* might be negligible, off-season harvesting could result in lower *machine rental costs*. A large influencing factor are *agricultural subsidies,* but also *lease cost/ha*, which are both affected by the APV-system.

6. Discussion

6.1. Technical system

Having the CLDs at hand makes the difficult task of optimizing these systems obvious. Small changes and optimizations in the PV-infrastructure (e.g. more modules, size of the plant) change the shading regime and thus directly impact agricultural production. In this context, panel density affects global radiation under APV more than panel management, e.g. by tracking (Amaducci et al., 2018). These interactions and their causal connections only become evident when visualizing all connections in a systems perspective as it confers a holistic view. Consequently, combined planning approaches for the agricultural and the power production systems (cf. Figs. 4 and 6) are necessary to optimize the APV-plant according to the local conditions (e.g. radiation, hedges, wind speeds etc.). The shading of the plants has a direct effect on the biomass yield (Innovation, 2017). Marrou et al. (2013a) conclude that the reduction of light mitigation is the most important aspect to pay attention to. Apart from this aspect, only minor changes in the agricultural production system would be required. To optimize the light penetration of crops, they suggest movable/mobile panels to minimize shading effects during planting time, while focusing on an optimal position for future energy production. For the optimization of the double harvesting, optimized light management includes different inclinations and panel distances compared to ground mounted PV-systems (Trommsdorff, 2016), allowing a more even distribution of solar radiation to achieve stronger and more stable plant growth. Such optimization comes at the expense of around 5% power production losses (Beck et al., 2012a) at a clearance height of ca. 6 m, which has proved suitable for all types of agricultural machines. Thus, the cultivation conditions for all crop types in potential crop rotations remain possible. The presence of balanced loops in the agricultural system stresses the importance of flexible system-design, as small changes in the set-up may affect other parts. Questions of optimization are driven by the power system, which may increase the biomass output economically (cf. Fig. 6, loops R3-R5). At the same time, APV equipped with solar tracking can lead to optimized production of electricity at the expense of the crop growth. On the other side, an optimized and controlled tracking mode potentially increases transmitted radiation at crop level to benefit crop growth (at the expense of the electric output) (Valle et al., 2017). Besides mounted PV-systems, there are Agrivoltaic systems with ground-mounted PV-modules which allow to use the area between the panels for farming. For these systems, the effects of the crops on the

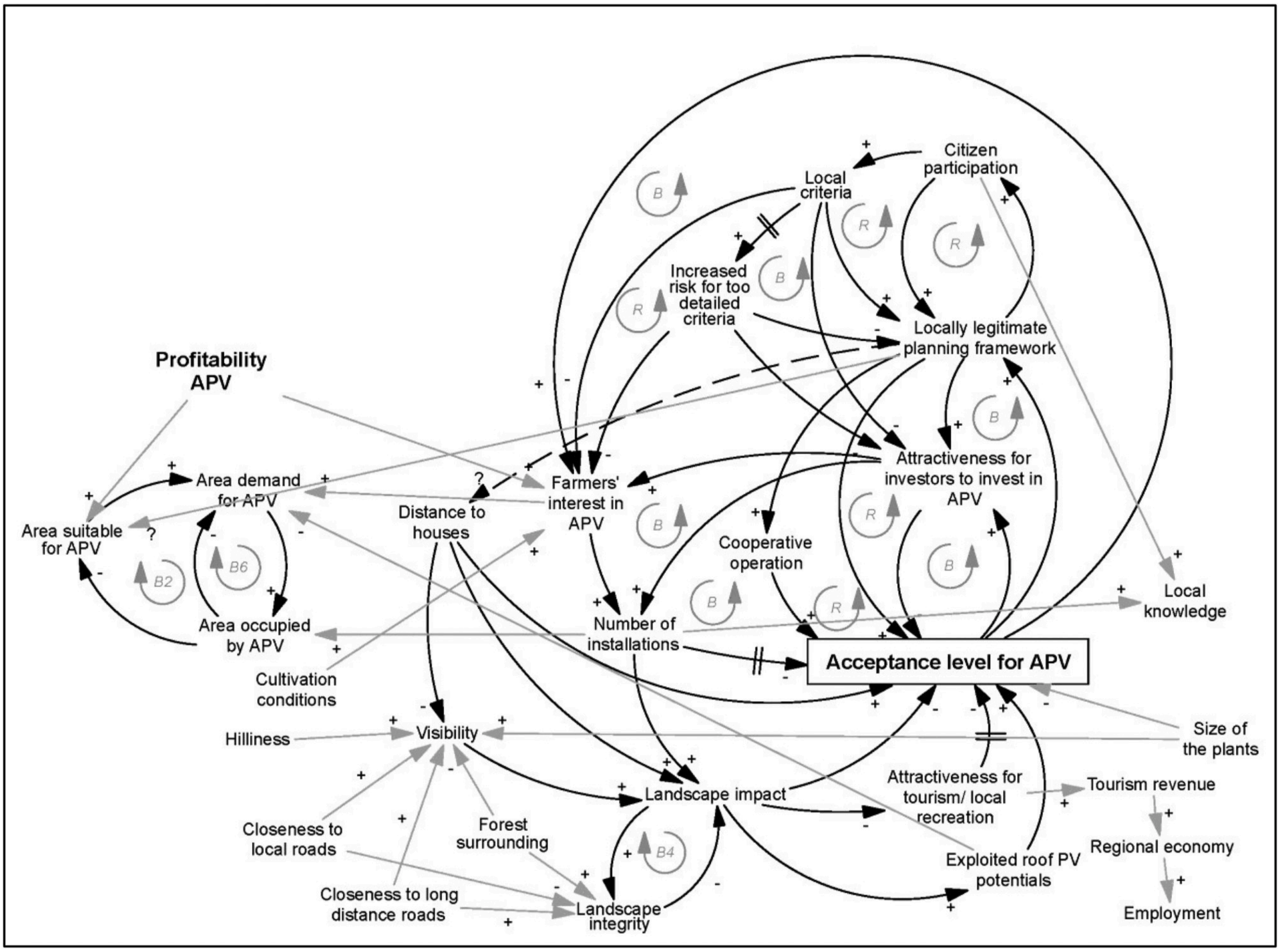

Fig. 5. Perception of APV-technology processes and drivers based on the participatory approach.

PV-system have been described by Dinesh and Pearce (2016): On the one hand, harvesting in the Agrivoltaic set-up could improve the temperature of the PV-modules; on the other hand, dust from agricultural operation may have negative effects. Therefore, these systems were not considered in the present paper. The multitude of factors defining the set-up of the APV-system and the agricultural cultivation show how difficult the adjustment and optimization of the system evolves due to their highly dynamic interplay. An opinion paper on APV highlights the important role of APV-systems for ecological and economical land use efficiency (Wuppertal Institut für Klima, Umwelt, Energie, 2014). When planning an APV-plant, the conditions on site must be carefully investigated to achieve an optimal functional interaction. The presented SD-approach revealed how these factors interact and how the system can be optimized and adapted to obtain beneficial set-ups. Counter-productive and opposing arrangements become apparent when following the CLD-structure. Thus, a thorough investigation and simulation can be facilitated by visualizing the magnitude of changes when making changes in one part of the system.

6.2. *Agricultural system*

These results represent the knowledge currently available for a climate region in southwest Germany (Lake Constanze) and are therefore not necessarily applicable to other locations and climatic conditions. For the pilot plant, a land use rate of 160% for APV could be demonstrated in 2017, i.e. 80% power production and slightly above 80% biomass production for the APV-system compared to separated agricultural and PV-systems (Fraunhofer Institute for Solar Energy Systems ISE, Freiburg. April 12th, 2019). This result was also discussed in the stakeholder workshop. The representative of the ministry assumed an increase of overall land efficiency by maybe 20%, while questioning the high land use rate found for 2017. Compared to ground-mounted PV, the APV visibility would be much higher, but accompanied by disadvantages for cultivation and high costs. In the very dry and hot summer of 2018, the land use rate even reached 186% when some crops had benefited from shading compared to the reference area (Fraunhofer Institute for Solar Energy Systems ISE, Freiburg. April 12th, 2019). The farmers' association was interested in long-term impacts on yields and assumed larger differences for traditional cultivation (as there was Demeter-cultivation at the pilot plant). In other set-ups, tests with agroforestry systems also shading crops led to lower grain yields near Montpellier (France) (Dufour et al., 2013). It has been estimated that shade protection can reduce the occurrence of e.g. water or nitrogen deficiency stress, so that plants might even benefit from PV-shading in heat stress (Dupraz et al., 2011; Marrou et al., 2013b). An analysis of eleven research and commercial APV-facilities and literature studies on shading effects in agriculture revealed a variety of results, which differ according to crop species and local climatic conditions (Weselek et al., 2019b). APV-systems equipped with tracking can optimize the availability of incident radiation for more efficient harvesting and electricity production (Valle et al., 2017). For wine or fruit production, PV may protect the plants from negative climatic effects, either directly or by supporting protection-grids (Weselek et al., 2019b). Further studies in different climate conditions (e.g. arid regions) on the combined systems are needed to generalize the trends. For a comprehensive analysis of the agricultural system the entire crop rotation has to be assessed.

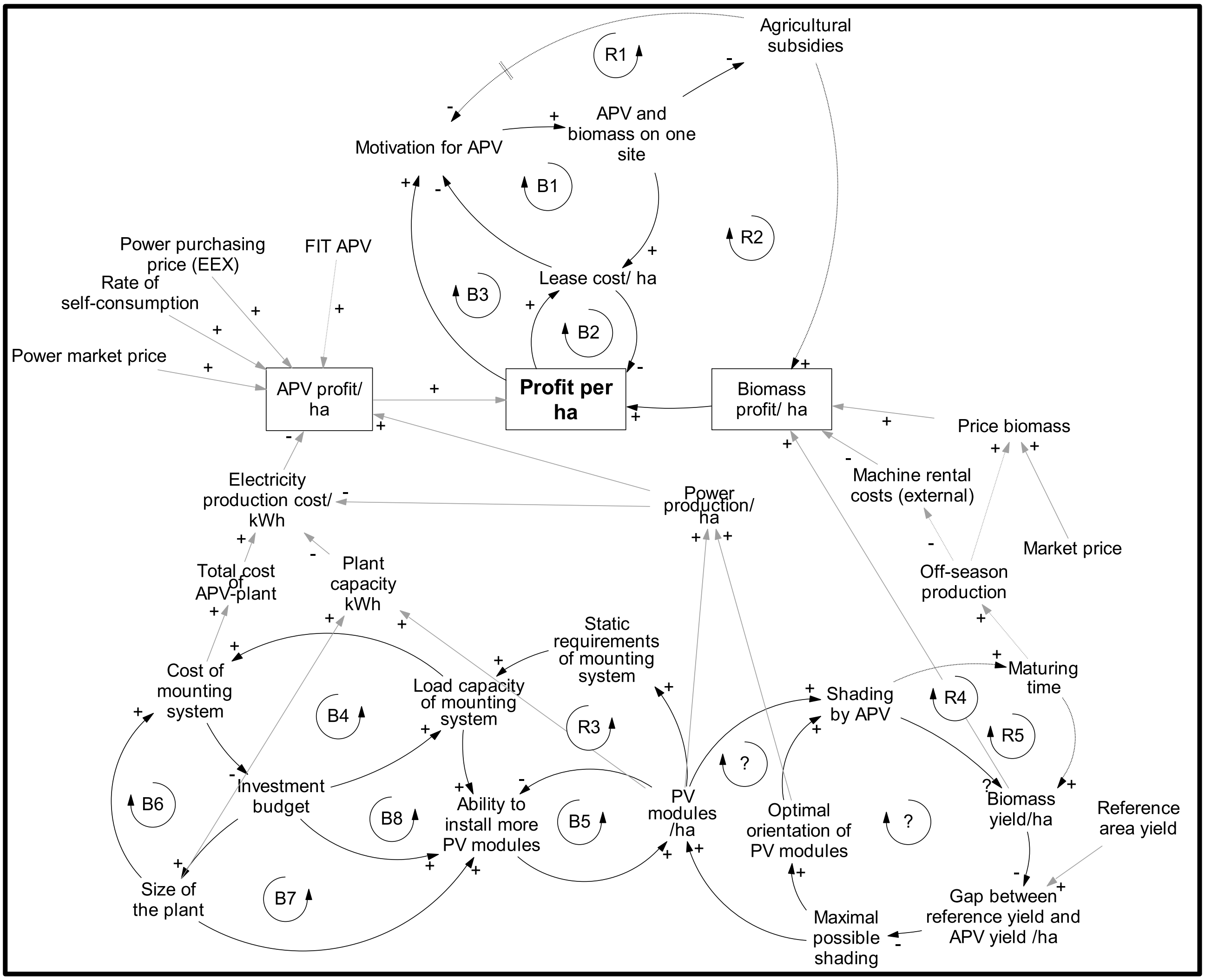

Fig. 6. Economic dynamics for the APV-technology.

6.3. Landscape impact

APV has significant visual impacts. This is certainly an important aspect of the technology that needs more thorough investigation. Citizen workshops have shown that the structure potentially negatively impacts landscape qualities vital to recreational and touristic areas. Similar discussions were also held on wind power installations (Smyth and Vanclay, 2017). The landscape impact highly depends on the site characteristics. In a hilly terrain, APV will be much more apparent than in plains (Ketzer et al., 2019). The question, if PV is integrated sensitively or insensitively in the landscape scenery, will strongly influence the impact and the level of acceptance. Situations of incompatibility are likely to occur. Existing features such as forest surroundings or hedgerow screening should be employed for visual mitigation and integration, but their efficiency will depend on local topography. The size of the plant will be a critical factor in this context. While large plants offer improved economic and cultivation conditions, the landscape impact will increase and lead to lower acceptance. Consequently, the siting of APV along roads was intensively discussed. On the one hand, installations along long-distance roads and railways with major visual impacts (similar to existing ground mounted PV) seem acceptable, as industrial areas are often built along long-distance routes anyway. On the other hand, a certain distance between the installations and the roads was considered necessary to avoid (massive) visual impacts and ensure that the quality of everyday life will not be affected. A currently uncertain question is whether a combination of energy crops (e.g. maize) with APV would lead to a direct decline in public acceptance. In WS 1, citizens argued they would not accept an APV-system that combines energy crops with PV. A sensitive design and choice of color of the structures may, to some extent, mitigate visual impacts.

6.4. Planning framework and acceptance level for APV

This analytical SD approach helps identifying strategies and recommendations for the development of APV-systems, and, equally important, strategies that are likely to be counterproductive. It shows that public perception is based on experience and attitudes, but also on the location of residence areas and a sense of the landscape. The question of social acceptance often focuses on energy related social science studies on a range of technologies (Devine-Wright et al., 2017). Studies on wind projects found that the lack of social acceptance is a major constraint, e.g. in France (Enevoldsen and Sovacool, 2016). Conversely, people's acceptance of and even identification with windfarms increases if they can invest themselves (Warren and McFadyen, 2010). The operation scheme for APV has been intensively discussed (e.g. investors vs. cooperative) (cf. Ketzer et al., 2019). Thus, the systematic identification of acceptance criteria is crucial for the development of functional policies and planning frameworks for publicly supported renewable energies. The CLDs visualize how different factors affect the local acceptance, which shows a strong reinforcing behavior (cf. Fig. 5, reinforcing loops): obviously, *citizen participation* is a key success factor for defining *local criteria* and a *locally legitimate planning framework*. In absence of participation or *cooperative operation* schemes, the *acceptance level* is likely to decrease strongly. In this context, energy cooperatives are often very site-specific as they reflect local conditions politically, structurally, and socio-economically (Moss et al., 2014). Even though the approach can be strongly supported by local citizens within a locally defined framework, they have identified the risk that local criteria will be over-defined resulting in a fragmented and paralyzing planning process. One criterion met with unanimous approval: APV is only acceptable as a new technology if all suitable roof, paved, hardened and industrial (brown field and sealed) areas have been exploited before any exploitation of the wider, agricultural, landscape (Ketzer et al., 2019).

In the case of APV, a number of factors are driving the acceptance of the technology. Even though the benefits of this co-production to reduce land use conflicts between biomass and power production were self-evident for the participants in the research process, this may lead to a conflict between production and visual landscape values. Apart from the landscape impact and the technical feasibility, a locally specified planning framework was identified as prerequisite for a high acceptance of APV. In this context, local criteria and practical knowledge (e.g. from farmers, municipal councils etc.) must be taken into account, but also the perception of out of area visitors and tourists whose acceptance may drive tourist related businesses. Early expansion of participation in both, the planning and the establishment of APV, is supposed to at least partially help to mitigate land use conflicts between energy and biomass production (Ketzer et al., 2019). Locally specified frameworks are expected to generally offer less opportunity to investors (who would benefit from a simple and uniform framework) and favor operations of local stakeholders, e.g. community-based cooperatives, which is usually seen as a fair and sustainable process. AEE (February 1st, 2018) emphasized that civic renewable energy is the key to the success of the Energiewende. Of all renewable power capacity installed, private individuals or farmers owned 42% in 2016 (AEE, 2018). The basis for citizens' acceptance and commitment depends on the question of how citizens can participate and invest (AEE, 2018). These findings were confirmed in the citizen workshops and the literature this study is based on.

6.5. *Conflicting objectives, optimization of APV, and limitations of this study*

The representation based on CLDs provides an overview of the interactions within the APV systems and illustrates difficulties in optimizing them. Each change potentially impacts several other parts of the system, which cannot be fully estimated yet due to a lack of experimental data. As there are only rare studies on suitable crops for APV-systems so far (cf. Weselek et al., 2019b), currently no general statements on the applicability of APV-systems on arable land can be made. The central question in this regard is the real purpose and benefit of APV-systems, especially concerning shading: on one hand, optimizing APV towards electricity output might lower biomass production; on the other hand, shading may improve biomass cultivation as it may reduce e.g. heat stress. As described by the CLDs, small changes in system design can lead to changes in both ways: APV may increase agricultural yields in one year, but reduce them in other years. However, adding more panels, improving the angle for PV etc., tends to have a negative effect on the agricultural system making the policy framework crucial for the system design. A modular design to adapt to local conditions is vital, while a flexible system can be used to optimize the agricultural system depending on the weather (cf. Valle et al., 2017). Finally, the results may be transferred to other regions with different local climatic conditions, while the general dynamics are assumed to be representative. Several other applications for APV (cf. Weselek et al., 2019b) may offer an extra potential. In order to fully exploit the APV-technology and ensure transferability, a systemic decision support tool bringing together decision criteria for the modular design of APV-systems would be beneficial.

7. Conclusion

The concept of Responsible Research and Innovation (RRI) aims at feeding in societal perceptions and future users' requirements into the technology designing process. In the case of APV, two usually independent systems are combined for producing biomass and power on the same piece of land. Possible impacts, system feedback and external perceptions have the potential to affect the entire system and lead to changes that might not be apparent immediately. Being in the development phase of APV, these interactions became visible thanks to the CLDs which offer an easy-to-understand systematic logic. CLDs allow stakeholders to follow linkages and feedback, thereby improving their ability to identify the various impacts of a change in one single factor or the effects of multiple combined change. Optimizing APV-systems is a highly complex question, as the harvesting periods of 2017 and 2018 show opposing results for the same shading set-up. If applied in other, warmer and dryer climatic zones (e.g. with higher shading tolerance), small system changes may potentially lead to different dynamics, e.g. by reducing water stress and thus increased yields. Nonetheless, local public acceptance is a key driving factor for success of a technology or opposition to it, which in turn is driven by a variety of details again. Against this background, this system's perspective facilitates an understanding of the causal connections between different site criteria. A commonly perceived risk concerns the optimization of the PV-system towards higher electricity production, which might lead to a significant reduction in biomass production being a restricting factor. Having noted this, the CLDs render a systemic representation of the system and the interaction of the parameters. Hence, this approach allows for bringing together new technologies or concepts comprehensively, capturing different stakeholder approaches to avoid missing aspects that might be easy to forget about. Besides the technical issues, the series of CLDs illustrates the importance and influence of local acceptance, planning frameworks and local knowledge as driving and restricting factors for the technology. Bringing stakeholders', citizens' and experts' perspectives into a system design allows for identifying the need for improvement in the technology and shape the required political framework.

Even though the basic relationships may be transferrable, some of the key driving forces and feedbacks need to be specifically assessed depending on local site conditions and crop type. Hence, this CLD-based representation underlines the need for a locally adapted framework, as the implementation of the APV-technology would lead to different outcomes in different regions. The strong dynamics between the systems and the partly large influence of an alteration of single factors might initially appear too complex to be solved. This is why leverage points need to be identified for which acceptance criteria for a sustainable framework could be developed. In order to provide detailed analyses, a decision support tool needs to be implemented supporting a wide array of stakeholders based on a quantitative model and relying on yield data, radiation data etc. and could easily be developed, if data is available. Given the dynamics of this design, the final scope depends on the policy framework. If APV was optimized towards electricity production, it might face public opposition, because the system would not comply with the combined system approach. On the other hand, if the protection of crops or other species against climate effects becomes a central element of policy, APV offers true benefits. Thus, optimization and system design must inevitably remain adjustable and modularized in order to meet local characteristics, changing demands and, in order to unfold its full potential, to be flexibly controlled according to weather conditions. As this study assessed the basic dynamics during the research phase of a pilot plant in the APV-RESOLA project, no quantitative results were available. Despite the lack of quantitative results, this study demonstrates a qualitative approach that allows for a thorough investigation involving both scientific and lay expertise (cf. Funtowicz and Ravetz, 1992) of the applicability of APV-systems in different contexts and regions, serving as a concept for sophisticated planning processes.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Daniel Ketzer: Conceptualization, Methodology, Resources, Visualization, Formal analysis, Writing - original draft. **Peter Schlyter:** Conceptualization, Writing - original draft, Funding acquisition, Supervision. **Nora Weinberger:** Resources, Methodology, Writing - review & editing, Funding acquisition, Project administration. **Christine Rösch:** Resources, Methodology, Writing - review & editing, Funding acquisition, Project administration, Supervision.

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Appendix A. Supplementary data

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References

AEE (February 1st, 2018. Bürgerenergie bleibt Schlüssel für erfolgreiche Energiewende. Available online at: https://www.unendlich-viel-energie.de/presse/pressemitteilungen/buergerenergie-bleibt-schluessel-fuer-erfolgreiche-energiewende?preview=1&token=2129c6bb078f7bcab1ddd196076cd59a.

AEE, 2018. GRAFIK-DOSSIER: ERNEUERBARE ENERGIEN IN BÜRGERHAND. Agentur für Erneuerbare Energien. Available online at: https://www.unendlich-viel-energie.de/mediathek/grafiken/grafik-dossier-erneuerbare-energien-in-buergerhand. checked on 9/30/2019.

Amaducci, Stefano, Yin, Xinyou, Colauzzi, Michele, 2018. Agrivoltaic systems to optimise land use for electric energy production. Appl. Energy 220, 545–561. https://doi.org/10.1016/j.apenergy.2018.03.081.

ARGE PV Monitoring, 2007. Leitfaden zur Berücksichtigung von Umweltbelangen bei der Planung von PV-Freiflächenanlagen. BMU. Available online at. http://www.naturschutzstandards-erneuerbarer-energien.de/images/literatur/pv_leitfaden[1].pdf. checked on August 18th, 2016.

Baffes, John, Haniotis, Tassos, 2010. Placing the 2006/08 Commodity Price Boom into Perspective. The World Bank.

Beck, M., Bopp, G., Goetzberger, A., Obergfell, T., Reise, C., Schindele, S., 2012a. Combining PV and food crops to Agrophotovoltaic – optimization of orientation and harvest. In: 27th European Photovoltaic Solar Energy Conference and Exhibition, vol. 5, pp. 4096–4100. https://doi.org/10.4229/27THEUPVSEC2012-5AV.2.25.

Beck, M., Bopp, Georg, Goetzberger, Adolf, Obergfell, Tabea, Reise, Christian, Schindele, 2012b. Combining PV and Food Crops to Agrophototaic - Optimization of Orientation and Harvest. Fraunhofer Institute for Solar Energy Systems ISE, Freiburg, Germany Staatliche Forschungsanstalt für Gartenbau Weihenstephan, Hochschule Weihenstephan-Triesdorf, Germany (0).

Bergmann, Ariel, Colombo, Sergio, Hanley, Nick, 2008. Rural versus urban preferences for renewable energy developments. Ecol. Econ. 65 (3), 616–625. https://doi.org/10.1016/j.ecolecon.2007.08.011.

BMWi, 2016a. Development of Renewable Energy Sources in Germany 2015. Charts and Figures Based on Statistical Data from the Working Group on Renewable Energy-Statistics (AGEE-Stat), as at February 2016. Federal Ministry for Economic Affairs and Energy. Available online at: https://www.bmwi.de/Redaktion/EN/Publikationen/renewable-energy-sources-in-figures-2017.pdf?__blob=publicationFile&v=3.

BMWi, 2016b. Federal ministry for economic Affairs and energy. EEG-Novelle 2017. Kernpunkte des Bundestagsbeschlusses vom 8.7.2016. Available online at: https://www.bmwi.de/BMWi/Redaktion/PDF/E/eeg-novelle-2017-eckpunkte-praesentation,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf. checked on August 24th, 2016.

BMWi, 2018. Renewable Energy Sources in Figures. National and International Development, 2017. Federal Ministry for Economic Affairs and Energy. Available online at. https://www.bmwi.de/Redaktion/EN/Publikationen/renewable-energy-sources-in-figures-2017.pdf?__blob=publicationFile&v=3. updated on September 2018, checked on July 28th, 2019.

Dehmer, Dagmar, 2016. Was das Windkraft-Urteil aus Bayern bedeutet. Der Ausbau der Windenergie ist wichtig für die Energiewende. Doch zwischen Wohnhäusern und Tierpopulationen wird der Platz knapp. In: Der Tagesspiegel, 5/11/2016. Available online at: https://www.tagesspiegel.de/politik/windenergie-und-die-10-h-regel-was-das-windkraft-urteil-aus-bayern-bedeutet/13571680.html.

Devine-Wright, Patrick, Batel, Susana, Aas, Oystein, Sovacool, Benjamin, Labelle, Michael Carnegie, Ruud, Audun, 2017. A conceptual framework for understanding the social acceptance of energy infrastructure. Insights from energy storage. In: Energy Policy, vol. 107, pp. 27–31. https://doi.org/10.1016/j.enpol.2017.04.020.

Dinesh, Harshavardhan, Pearce, Joshua M., 2016. The potential of agrivoltaic systems. In: Renewable and Sustainable Energy Reviews, vol. 54, pp. 299–308. https://doi.org/10.1016/j.rser.2015.10.024.

Dufour, L., Metay, A., Talbot, G., Dupraz, C., 2013. Assessing light competition for cereal production in temperate agroforestry systems using experimentation and crop modelling. J. Agron. Crop Sci. 199 (3), 217–227. https://doi.org/10.1111/jac.12008.

Dupraz, C., Marrou, H., Talbot, G., Dufour, L., Nogier, a., Ferard, Y., 2011. Combining solar photovoltaic panels and food crops for optimising land use: towards new agrivoltaic schemes. Renew. Energy 36 (10), 2725–2732. https://doi.org/10.1016/j.renene.2011.03.005.

EEA, 2011. Land Use Conflicts Necessitate Integrated Policy. European Environmental Agency. Available online at: https://www.eea.europa.eu/highlights/land-use-conflicts-necessitate-integrated-policy. updated on 6/21/2016, checked on 9/30/2019.

Enevoldsen, Peter, Sovacool, Benjamin K., 2016. Examining the social acceptance of wind energy. Practical guidelines for onshore wind project development in France. In: Renewable and Sustainable Energy Reviews, vol. 53, pp. 178–184. https://doi.org/10.1016/j.rser.2015.08.041.

FNR, 2019. Flächennutzung in deutschland. Fachagentur für Nachwachsende Rohstoffe e.V. Available online at: https://mediathek.fnr.de/grafiken/daten-und-fakten/anbau/flachennutzung-in-deutschland.html. updated on 2019, checked on July 28th, 2019.

Fraunhofer ISE, April 12th, 2019. Agrophotovoltaik: hohe Ernteerträge im Hitzesommer. Fraunhofer Institute for Solar Energy Systems ISE, Freiburg, Germany. In: Fraunhofer Institute for Solar Energy Systems ISE. Freiburg, Germany. Available online at. https://www.ise.fraunhofer.de/content/dam/ise/de/documents/presseinformationen/2019/1019_ISE_d_PI_APV_Projektabschluss.pdf. checked on June 21st, 2019.

Funtowicz, Silvio O., Ravetz, Jerome R., 1992. The good, the true and the post-modern. Futures 24 (10), 963–976. https://doi.org/10.1016/0016-3287(92)90131-X.

Goetzberger, Adolf, Zastrow, A., 1982. On the coexistence of solar-energy conversion and plant cultivation. Int. J. Sol. Energy 1 (1), 55–69. https://doi.org/10.1080/01425918208909875.

Grunwald, Armin, 2010. Technikfolgenabschätzung - eine Einführung. 2., grundlegend überarb. u. wesentlich erw. Aufl. In: Sigma (Ed.), vol. 1. Gesellschaft - Technik - Umwelt, n.F., Berlin.

Haraldsson, Hördur V., 2000. Introduction to systems and causal loop diagrams. In: System Dynamic Course, Lumes. Lund University, Sweden.

Harvey, Mark, Pilgrim, Sarah, 2011. The new competition for land. Food, energy, and climate change. Food Pol. 36, S40–S51. https://doi.org/10.1016/j.foodpol.2010.11.009.

Hübner, Gundula, Pohl, Johannes, 2015. Mehr Abstand-Mehr Akzeptanz? Ein Umweltpsychologischer Studienvergleich: Fachagentur Windenergie an Land.

Innovation 4E, 2017. Agrophotovoltaics: Harvesting the Sun for Power and Produce. Available online at. http://blog.innovation4e.de/en/2017/12/01/agrophotovoltaics-harvesting-the-sun-for-power-and-produce/. checked on April 6th, 2018.

IRENA, 2019. Renewable Power Generation Costs in 2018 (Abu Dhabi).

Kelm, Tobias, Metzger, Jochen, Fuchs, Anna-Lena, Schicketanz, Sven, Günnewig, Dieter, Thylmann, Miron, 2019. Untersuchung zur Wirkung veränderter Flächenrestriktionen für PV-Freiflächenanlagen. Kurzstudie im Auftrag der innogy SE. Zentrum für Sonnenenergie- und Wasserstoff-Forschung (ZSW); Bosch & Partner GmbH. Available online at. https://www.zsw-635bw.de/fileadmin/user_upload/PDFs/Aktuelles/2019/politischer-dialog-pv-freiflaechenanlagen-studie-333788.pdf.

Ketzer, Daniel, Weinberger, Nora, Rösch, Christine, Seitz, Stefanie, 2019. Land use conflicts between biomass and power production - citizen participation in the technology development of agrophotovoltaics. Journal of Responsible Innovation. https://doi.org/10.1080/23299460.2019.1647085.

Kroll, Franziska, Haase, Dagmar, 2010. Does demographic change affect land use patterns? Land Use Pol. 27 (3), 726–737. https://doi.org/10.1016/j.landusepol.2009.10.001.

Maani, K., Cavana, R.Y., 2000. Systems Thinking and Modelling: Understanding Change and Complexity (Great Britain).

Marcheggiani, Ernesto, Gulinck, Hubert, Galli, Andrea, 2013. Detection of Fast Landscape Changes. The Case of Solar Modules on Agricultural Land General Problem Setting : Fast Changes on Arable Lands, pp. 315–327.

Marrou, H., Guilioni, L., Dufour, L., Dupraz, C., Wery, J., 2013a. Microclimate under agrivoltaic systems: is crop growth rate affected in the partial shade of solar panels ? Agric. For. Meteorol. 177, 117–132.

Marrou, H., Wery, J., Dufour, L., Dupraz, C., 2013b. Productivity and radiation use efficiency of lettuces grown in the partial shade of photovoltaic panels. Eur. J. Agron. 44, 54–66. https://doi.org/10.1016/j.eja.2012.08.003.

Mason, Pamela, Lang, Tim, 2017. Sustainable diets. How Ecological Nutrition Can Transform Consumption and the Food System/Pamela Mason, Tim Lang. Routledge, London.

Meadows, Donella H., 1999. Leverage Points. Places to Intervene in a System.

Movellan, Junko, 2013. Japan Next-Generation Farmers Cultivate Crops and Solar Energy. Available online at. http://www.renewableenergyworld.com/rea/news/article/2013/10/japan-next-generation-farmers-cultivate-agriculture-and-solar-energy.

Moss, Timothy, Becker, Sören, Naumann, Matthias, 2014. Whose energy transition is it, anyway? Organisation and ownership of the Energiewende in villages, cities and regions. Local Environ. 20 (12), 1547–1563. https://doi.org/10.1080/13549839.2014.915799.

Musall, Fabian David, Kuik, Onno, 2011. Local acceptance of renewable energy - a case study from southeast Germany. Energy Pol. 39 (6), 3252–3260. https://doi.org/10.1016/j.enpol.2011.03.017.

Rösch, Christine, 2016. Agrophotovoltaik - die Energiewende in der Landwirtschaft. In: GAIA - Ecological Perspectives for Science and Society, vol. 25, pp. 242–246. https://doi.org/10.14512/gaia.25.4.5, 4.

Schindele, Stephan, Bopp, G., Essam, R., Goetzberger, A., Obergfell, T., Reise, Ch, 2014. Agrophotovoltaic (APV) – agricultural production below optimized elevated photovoltaic systems. In: Agrophotovoltaics in the MENA Region. Profitable Applications for Egypt. Workshop Heliopolis University Campus, Cairo, Egypt.

Schlyter, Peter, Stjernquist, Ingrid, Sverdrup, Harald (Eds.), 2012. Handling Complex Environmental Issues–Formal Group Modelling as a Deliberative Platform at the Science-Policydemocracy Interface.

Schweizer, Pia-Johanna, Renn, Ortwin, Köck, Wolfgang, Bovet, Jana, Benighaus, Christina, Scheel, Oliver, Schröter, Regina, 2016. Public participation for infrastructure planning in the context of the German "Energiewende". In: Utilities Policy, vol. 43, pp. 206–209. https://doi.org/10.1016/j.jup.2014.07.005.

Smyth, Eddie, Vanclay, Frank, 2017. The Social Framework for Projects. A conceptual but practical model to assist in assessing, planning and managing the social impacts of projects. Impact Assess. Proj. Apprais. 35 (1), 65–80. https://doi.org/10.1080/14615517.2016.1271539.

Staniszewska, Monika, 2014. Nimby syndrome as an example of a social conflict with local characteristics. Acta Innovations (12), 17–23.

Sterman, John, 2000. Business Dynamics. Systems Thinking and Modeling for a Complex World. Irwin/McGraw-Hill, Boston.

Sterman, John D., 2001. System dynamics modeling. Tools for learning in a complex world. Calif. Manag. Rev. 43 (4), 8–25. https://doi.org/10.2307/41166098.

Sverdrup, H., Belyazid, S., Koca, D., Jönsson-Belyazid, U., Schlyter, P., Stjernquist, I. (Eds.), 2010. Miljömål i fjällandskapet. En syntes av problemställningar knutna till förvaltningen av en begränsad resurs, vol. 6366. Naturvårdsverket (Rapport/Naturvårdsverket, Stockholm.

Trommsdorff, Maximillian, 2016. An economic analysis of agrophotovoltaics: opportunities, risks and strategies towards a more efficient land use. In: The Constitutional Economics Network Working Papers. Freiburg (03-2016). Available online at: http://hdl.handle.net/10419/150976.

Valle, B., Simonneau, T., Sourd, F., Pechier, P., Hamard, P., Frisson, T., et al., 2017. Increasing the total productivity of a land by combining mobile photovoltaic panels and food crops. Appl. Energy 206, 1495–1507. https://doi.org/10.1016/j.apenergy.2017.09.113.

Vennix, J.A.M., 1996. Group model building. Available online at: http://www.eolss.net/sample-chapters/c15/E6-63-05-05.pdf.

Warren, Charles R., McFadyen, Malcolm, 2010. Does community ownership affect public attitudes to wind energy? A case study from south-west Scotland. Land Use Pol. 27 (2), 204–213. https://doi.org/10.1016/j.landusepol.2008.12.010.

Weselek, Axel, Ehmann, Andrea, Zikeli, Sabine, Lewandowski, Iris, Högy, Petra, 2019a. Agrophotovoltaik-Auswirkungen auf Mikroklima und landwirtschaftliche Erträge. In: Innovatives Denken für eine nachhaltige Land-und Ernährungswirtschaft. Beiträge zur 15, vol. 5. Wissenschaftstagung Ökologischer Landbau, Kassel bis 8. März 2019.

Weselek, Axel, Ehmann, Andrea, Zikeli, Sabine, Lewandowski, Iris, Schindele, Stephan, Högy, Petra, 2019b. Agrophotovoltaic systems. Applications, challenges, and opportunities. A review. In: Agronomy for Sustainable Development, vol. 39, p. 35. https://doi.org/10.1007/s13593-019-0581-3, 4.

Degraded land and sustainable bioenergy feedstock production. In: Wiegmann, Kirsten, Hennenberg, Klaus J., Fritsche, Uwe R. (Eds.), 2008. Issue Paper of the Joint International Workshop on High Nature Value Criteria and Potential for Sustainable Use of Degraded Lands. Öko-Institut, Paris. June 30 - July 1, 2008. Darmstadt.

Withers, Paul, Neal, Colin, Jarvie, Helen, Doody, Donnacha, 2014. Agriculture and eutrophication. Where do we go from here? Sustainability 6 (9), 5853–5875. https://doi.org/10.3390/su6095853.

Wuppertal Institut für Klima, Umwelt, Energie, 2014. Stellungnahme zur BMWi-Konsultation "Eckpunkte für ein Ausschreibungsdesign für Photovoltaik-Freiflächenanlagen. In: Agrophotovoltaik (APV) Als Ressourceneffiziente Landnutzung. Wuppertal. Available online at: http://nbn-resolving.de/urn:nbn:de:bsz:wup4-opus-55473.

Ziemann, Saskia, Ketzer, Daniel, Young, Steven, Weil, Marcel, Poganietz, Witold-Roger, 2016. Increased lifetime and resource efficiency in electric mobility - linking material flow analysis with system dynamics. In: Ulrich, Teipel, Reller, Armin (Eds.), Rohstoffeffizienz und Rohstoffinnovationen. Band 4. Fraunhofer IRB Verlag, Stuttgart, pp. 153–168.