Integrating sustainability at the front end of system innovations in agriculture using a triple-helix approach

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Abstract: *With current farm management practices exceeding global natural resources capacities, there is an increasing societal interest in innovative approaches that support a transition to sustainable agricultural systems. An out-of-niche development of such innovations is, however, challenged by a very high standardisation of food value chains, lock-in effects and a lack of infrastructure available for an integration of small-scale production systems. In addition to this comes a limited knowledge of potentials and impacts on the side of the actors involved in developing the innovation. The objective of this study was to integrate sustainability in the innovation process by applying a systems view of foresight in an early stage of innovation development. For this end, we set up a back-casting process based on a triple-helix approach that was adapted to the agricultural setting by including science, policy and agricultural practice. We deliberately selected four conceptual sustainability-oriented innovations that were driven by the motivation of actors in agricultural science and practice. Based on interviews and focus group workshops we identified short term and long term goals relevant in each case, and described the potentials and challenges perceived in relation to the success of the innovation as well as the sustainability aims. We discuss the challenges faced within a directional goal-oriented innovation process derived from the triple-helix interaction. We show that the transformation process involves systemic shifts at different levels, and that actors need to address a) the potential for directional change, b) ecosystem intervention, c) economic trade-offs, and d) impact assessment complexity.*

Keywords: *system innovation, foresight, land use, innovation system, impact assessment, triple-helix*

Introduction

Agricultural land use research and development strategies in the European Union and member states have taken up the request that innovation has a major contribution to make in adapting land-use to an improved conservation of local natural resources next to the current developments of markets, thereby addressing grand challenges such as sustainability, food security and climate change (e.g. Horizon 2020, European Innovation Partnership) (EEA 2013, Leach et al. 2012, McIntyre et al. 2009). Consequentially, from the perspective of farmers, the question is how these challenges can be addressed through innovative changes that achieve a positive-sum game in economic terms. For those shaping the conditions for so-called sustainability innovations, directionality is one crucial aspect in the management of innovations that serve a specific cause (Weber and Rohracher 2012). One possible entry point to a justification of sustainability innovations in the field of land use is the reflection of underlying societal values of local actors against the concept of sustainability. Ideally, sustainability innovations address the above mentioned challenges by making use of the local capacities to define, promote and reinforce sustainable agricultural systems. These reinforcing mechanisms presume the co-production of public and private economic and social values next to a market value (Di Iacovo et al. 2016; Manson et al. 2016). Sustainable agricultural systems embedded in wider land management are considered particularly relevant in regions with a rich cultural landscape formed and influenced by decades of farming practice (e.g. Plummer et al. 2008). How directionality of innovation activities towards sustainable agricultural systems can be achieved within a complex and interdependent land use, is hence a relevant research topic in the field of agricultural innovation.

The research topic is widely addressed in different research fields dealing with sustainability innovations, agricultural innovation and the interplay and management of interaction in innovation processes. Goal-oriented innovation research has a theoretical foundation in different scholarly fields, such as multi-level system dynamics (Geels 2004; Kropff et al. 2001) or governance for sustainable development (Ashford & Hall 2011; Newig et al. 2008). Weber und Rohracher (2012) conceptually link innovation systems and transition research with regard to sustainability. Changes in production, organisation and natural-resource allocation are regarded as system innovations that require a broad management process involving actors across different sectors and decision making levels to become effective (Elzen et al. 2004; Geels 2005). However, research on existing model approaches shows that an out-of-niche development of such innovations is often challenged by lock-in effects of existing value chains and limited knowledge of potentials and impact on the side of the actors involved in developing the innovation (Manson et al. 2016; Nelson et al. 2014, Fichter and Clausen 2013). In addition to this, the actors involved in developing the innovation often have a limited knowledge of potentials and impacts on the environment, so that sustainability trade-offs come along as unintended side effects. Researchers are given a key role as innovation brokers, mediators and co-developers that act in cooperation with local actors, while land managers, policy makers and residents are considered as influencers to the process who define the surrounding sphere in which an innovation can thrive (Klerkx & Leeuwis 2008; Läpple et al. 2016). Such systems perspectives demonstrate the need to involve representatives from all groups into innovation processes at the earliest possible stage to avoid too many trial-and-error approaches before achieving user adoption and market entrance. The triple-helix-approach (Leydesdorff & Etzkowitz 1996) provides a framework that focuses on more efficient innovation processes in multi-actor settings. Furthermore, innovations in agriculture that target sustainability in the agricultural system additionally require an early understanding of potential impacts on the environment.

This study sets out to analyse the early planning stages of four cases by taking a systems perspective on innovations in agriculture. We address this by applying an expert-based foresight analysis to the front-end of the sustainability-oriented innovation processes. We thereby address the following research questions:

a) What short-term and long-term goals are perceived relevant by the actors involved in the development of the innovation?

b) How can sustainability considerations be integrated at an early planning stage through operationalizing a triple-helix approach?

To address this question related to innovation management, we apply a methodological approach at middle grain or meso-level, thereby allowing for an analysis of the interplay between and within different groups of actors and the challenges involved in steering innovations towards sustainability in multi-actor contexts.

The front end of innovation in management concepts

Given that innovative initiatives ever so often fail before reaching a market of users or consumers (Fichter and Clausen 2013), ideally the sound preparation of an innovation process already in early stages may avoid later misalignment between strategies, unexpected lack of resources availability or counteractive target-setting between actors involved. From an entrepreneurial innovation research perspective, the purpose of activities at the front end is first and foremost driven by entrepreneurial thinking: to prioritise next steps and development options by screening and repositioning the innovation in relation to known and assumed contextual factors, associated actors and resources. In innovation management models, the front end explicitly specifies a knowledge-intensive and weakly structured stage in an innovation process, e.g. Stage-Gate (Cooper and Kleinschmidt 1986), New Product Development (Ford et al. 2016; Jetter & Sperry 2009) and Business Model Innovation (Günzel & Holm 2013).

Classic front end activities as described by Koen et al. (2001) involve five elements that take place simultaneously: opportunity identification, opportunity analysis, idea genesis, idea selection, and concept and technology development. The front end analysis is completed when an idea or invention can be articulated in form of a well-defined concept or roadmap that includes timely and specific goals, and ideally attains investment and resources for further development. The combination of action-oriented activities such as idea generation and concept development next to assessment-oriented activities such as analysis and selection adds to the non-linear and unstructured nature of the process in its early stage.

The particular vagueness in early innovation development stages is recognised both in concepts related to the Innovations Systems Framework (e.g. Anadon et al. 2014) as well as in linear process developments such as stage-gate processes (e.g. Cooper et al. 2002). Although more prominently associated with linear concepts, where front end innovation is understood as a defined and temporary phase that takes place before product development and market entry, concepts that take a systems perspective link this phase also to later stages of development (Anadon et al. 2014). Hence, early stage challenges or front end phenomena of innovation management can occur at different phases of innovation processes, for example when product-development goals are refined or when the set of actors involved undergoes changes.

The triple-helix approach applied to sustainability-oriented innovations

To conceptualise the mentioned management of innovation activities, we embed the methodology in the so called Triple Helix Approach (Leydesdorff & Etzkowitz 1996). It adds a further dimension to the innovation process, namely the need to navigate between science and markets through interaction between actors from different domains such as universities, industries and government. A helix model stands for the evolution of multiple linkages between different actors at different stages of an innovation process (Leydesdorff & Etzkowitz 1996). Circulation along the helix between the domains of research, industry and government is considered a basic premise of development. The approach has developed in parallel to other relevant concepts spanning from linear to open innovation. Its key claim is that institutional structures become ill-adapted to current situations, new structures co-evolve to temporarily resolve the mismatch, before again the new structures become themselves out of match. It thereby addresses the concrete problem of "endless transition" within and between research, industry and government by stimulating response to changing cognitive, technical, economic and international trends in a cyclic process (Shinn 2002).

In further development of the approach, a set of institutional components with interlinked relationships and predefined functions as input resulted in the Triple Helix System of Innovation (Ranga and Etzkowitz 2013). Its main function is the generation, diffusion and utilisation of knowledge. Thereby, it can be synthesised to fit the institutional relationships driven by a specific innovation process with set targets (e.g. sustainability). In this manner, the triple helix provides a flexible yet explicit framework to identify existing challenges, blockages or gaps in the innovation process, and to potentially generate new combinations of knowledge and resources. Given the multi-actor nature of agricultural innovation, we propose to apply this approach to the four cases of sustainability-oriented innovation in agriculture.

Selection of case studies

Four case studies were selected upon a deliberate search for innovative approaches that were being developed in the agricultural sector in north-eastern Germany. The selection was determined by the innovations potential for supporting a transition to sustainable agricultural systems, as perceived by the actors involved. Furthermore, the selection was determined by the need for a front end analysis, indicated by an unspecified request for additional (experimental) research, consultation, monitoring, funding, investor-relationships and expertise for further development and implementation. All case studies were found to represent the typical initial complexity of a systemic innovation process in agriculture, with particular difficulties in establishing the innovation as an alternative to existing production and value chains, and in reaching competitive economic scale. The case studies were finally selected because of the relevance of the problem they addressed. In all selected case studies, the targeted problems were understood to be relevant to a niche sector, but were likely to become increasingly relevant under on-going global changes, such as climate change, food security or migration to urban areas.

1) EVI: a biological control agent for soil-borne pathogen regulation (2009-2014);

2) ASTAF Pro: a double recirculation system for aquaponic systems (2009-2014);

3) EiCare: the re-introduction of dual-purpose poultry production systems (2014-2019);

4) HayHeat: a small-scale thermal production from biomass in marginal grassland (2014-2019).

The case studies were analysed for approximately five years in the frame of third-party funded projects financed by national German ministries in order to improve innovation processes in agriculture. At the outset, each case study was found at a different state of development. Also, the objectives differed (Table 1). Objectives and focus for further development were determined by the project team together with the main actors in the innovation system.

Table 1. Overview of case study settings

Case Study	Promotion of initiative	Orientation of Intervention	State of development at the outset	Objective
1. EVI	Science driven	Spatial (Wilt infested fields in Brandenburg)	Patented technology based on agro-ecological principles	Feasibility in agricultural practice
2. ASTAF	Science driven	Sector	Patented technology and	Cost- and resources

	Pro		(Horticulture and Aquaculture)	concept for a model of multi-functional agriculture	efficiency
3.	**EiCare**	Practice driven	Sector (Poultry)	Limited adoption of a model for multi-functional agriculture	Scalability and out-of-niche development
4.	**HayHeat**	Practice driven	Spatial (Biosphere Reserve Spreewald)	Feasible technology and concept for multifunctional agriculture	Proof-of-concept and implementation by first adopter

Design and implementation of the foresight process

Foresight is based on the assumption that the future can be shaped in positive ways, i.e. along the set of values, by an improved understanding of options and risks, driving forces and underlying processes of change (Dufva & Ahlqvist 2015). A reflexive element can be included by back-casting (Popper 2008). A back-casting viewpoint is taken, where at the time of planning future scenarios are envisioned and impacts are illustrated to provide choice options. The benefit of the structured process in systemic foresight is that it creates a “virtual third party” by bringing together all relevant perspectives that stand representative for society. Thus, the innovation is assessed against the societal values by the involvement of a small subset of actors. The second benefit of the process is that it allows for a consideration of externalities at this early development stage.

While a product innovation first of all has to pass against market requirements, the innovative approaches presented here have to additionally pass against societal values and sustainability aims. However, none of the actors have full knowledge of the whole system and its internal and external influencing factors. Stage-gate processes generally assume a company or firm with a middle management that representatively takes decisions to develop an innovation (Cooper et al. 2002). In the innovation systems framework, intermediaries take over this role (Klerkx & Leeuwis 2008). Intermediaries are individuals or organisations that are knowledgeable of the issue but stand outside the immediate network of actors involved with developing the innovation. In our case, research projects as a temporal organisation took over this task. With the intention to cover the front end of innovation, we developed a foresight process based on three basic scoping elements by Popper (2008).

Step 1: *Selection of actors*

The foresight team was determined by the function of the actors in relation to the innovation indicated by the actors’ personal investment and concern in the development of the innovation. Following this functional approach, we considered three basic groups: 1) Inventors and champion promoters of an innovation (principal actors) who are considered key carriers of knowledge regarding the historic development of the innovation, the previously existing and foreseen agricultural production processes, and the sustainability challenge targeted in the context of the agricultural system; 2) Implementers and managers of the innovation (direct actors) who as a group are knowledgeable of technical and developmental aspects as well as potential risks linked to the innovation; and 3) Actors affected by the innovation in a positive or negative way (indirect actors). Overall, 52 guided expert interviews were conducted. The interviews sought to identify the relationships, motivations and functions of actors in regard to the innovation. Furthermore, they were used to identify further the potential opportunities and risks perceived by the individual actors (Table 2). The interviews were transcribed and used as a database in the subsequent foresight process.

Table 2. Actors involved in the innovation case study research.

Case study		Principal actor	Direct actors	Indirect actors	Interv iews
1.	**EVI**	Leibniz-Centre for	Farmers with a history of	Authorities for crop	13

		Agricultural Landscape Research (ZALF)	strawberry production and field disease infestation in Brandenburg; Manufacturer of biological soil conditioners	protection Extension services Consultancies Strawberry breeders	
2.	**ASTAF Pro**	Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB)	Researchers involved in the invention and implementation of the aquaponic system	Aquaculture production Vegetable production Greenhouse engineering and design	11
3.	**EiCare**	Marktgesellschaft der Naturland Bauern AG and terra Naturkost (Marketing organisations)	Farmers in poultry production with a herd size of <1000 hens produced and marketed in cooperation with Naturland	Processors (meat) Extension services Breeders Retailers	13
4.	**HayHeat**	UNESCO Biosphere Reserve Spree Woods, State Office for Environment	Smallholder farmers with joint land ownership of 1000 ha in the Spree Woods/Błota	Tourism Nature conservation Hunters and fishermen	15

Step 2: *Definition of goals*

The transcribed interviews were used to assess in more detail the state of development at the outset of the innovation process, and to identify the objectives related to the short- and long-term. The results were discussed in focus groups with the interviewed actors to establish a joint knowledge base. Innovative aspects were made explicit, and objectives were discussed. We distinguished two types of objectives to be addressed in the process: 1) innovation management goals, and 2) sustainability goals. The innovation management goals relate to the invention and its development into new products and services embedded in a market environment. Sustainability goals relate to the function of the invention within the wider context of the sector and region, and eventually the transition to sustainable agricultural systems. The back-casting exercise took account of this differentiation by taking a short-term viewpoint for identifying innovation management goals, and a long-term viewpoint for the sustainability goals.

Step 3: *Design of the foresight process*

Lastly, the systemic foresight process was designed based on methods suitable to the context and need of the actors. The implementation of the foresight process was conducted as part of an inter- and transdisciplinary project approach leaning on methods of participatory research, action research and sustainability assessment, whereby an analysis of the functional relationship of the actors to the value chain and a collaborative situation analysis with expert interviews and focus group workshops were applied (König et al. 2013, König et al. 2015, König et al. 2016). The focus group workshops in all four cases were steered by an external moderator. The process was underpinned by regular meetings for scientific reflection, thereby allowing the project team to participate in the design of the assessment framework. The workshops were set up to provide actor-based information for all the relevant elements of front end assessment: a) supports opportunity identification by bringing together a diverse range of actor perspectives, b) back the assessment and selection of ideas through clarification of innovation management goals, and c) assist the specification of the concept by considering sustainability goals. The aim was to identify the potentials and challenges in regard to the success of the innovation and the sustainability aims.

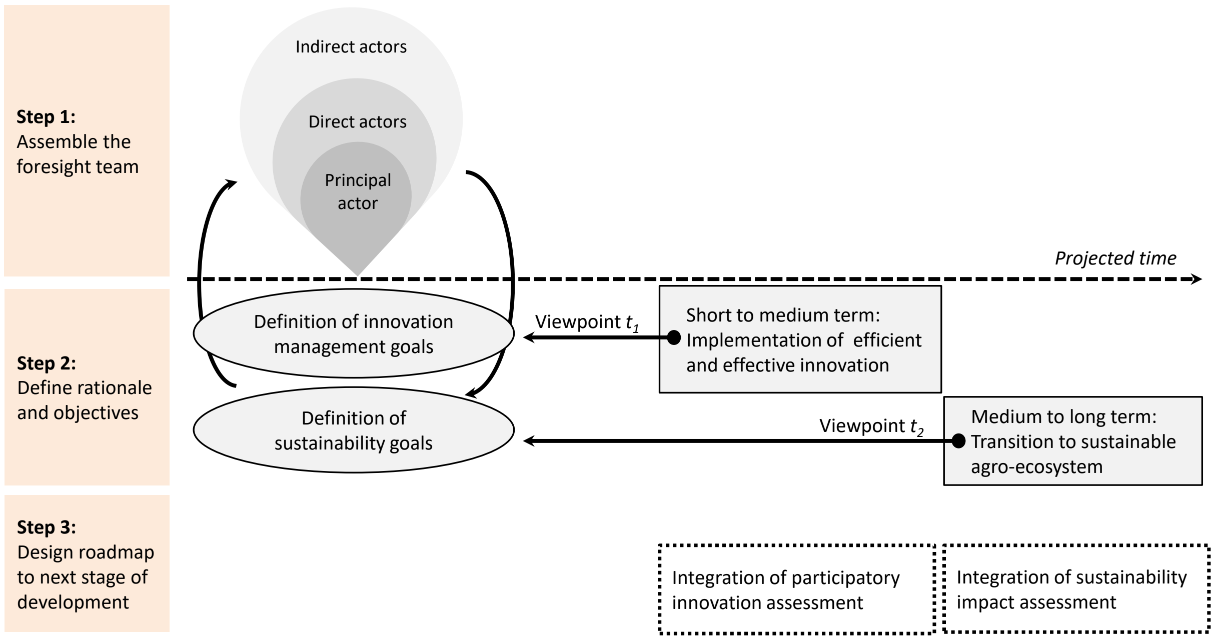

Figure 1. Integration of target knowledge in a foresight process for front end innovation assessment using back-casting (authors own compilation). Viewpoints t1 and t2 describe the user perspective taken from a later stage of the process.

Results

Definition of goals: The interviews were analysed with regard to the short term and long term goals of the actors involved in the innovation process (Table 3). The interview results relate to Step 2 in Figure 1.

Due to a general lack in risk capital available for the farms involved in the case studies, no farmer or actor could afford innovation development as an individual. However, non-farm investors required further proof-of-concept in production site field trials as well as economic scope. This became particularly apparent in case study 2, due to high investment costs in greenhouse production. In consequence, all involved farmers required technically and financially viable solutions aimed at safeguarding existing production chains and hedging their financial risks in terms of guarantees, e.g. by guaranteed purchase of meat and eggs through the marketing organisations in case study 3. Farmers felt especially challenged by shortfalls in production that were partly influenced by their motivation to produce under frameworks of sustainable production, such as the rules for organic production of eggs and meat by Naturland in case study 3, or the rules for grassland management within the Biosphere Reserve in case study 4. Further challenges were perceived due to insufficient infrastructure and value chain linkage, particularly in the case studies involving food products (cases 1, 2 and 3). Other requirements involved the development of more efficient distribution channels as well as regular and continuous supplies. Short-term goals mainly addressed an achievement of proof-of-concept and an assessment of potentials for regional up-scale. Long-term goals overall included the maintenance of extensive farming practices, and functioning circular material flows with little waste or surplus production, including local supplies and local marketing. Furthermore, all actors sought to maintain or achieve capacities to react flexibly to markets, persist and further develop the innovation, and eventually contribute to its expansion in the long run.

Table 3. Innovation management goals (short term) and sustainability goals (long-term).

Case Study	Short-term goals	Long-term goals
1. EVI	Develop a viable substrate for field application to regulate Verticillium wilt in strawberries.	Transfer of technology to commercial strawberry production. Improve viability of strawberry production in

		Test the technology in cooperation with farmers. Assess efficiency and effectiveness in commercial strawberry production.	regional production sites with high risk of *Verticillium* infestation.
2.	**ASTAF Pro**	Identify suitable first adopters. Assess suitable sector niche and product vision for commercial business case development. Develop setting for proof-of concept for feasibility and commercial viability of the concept.	Organic and local production of vegetables and fish in specific local settings (e.g. urban, arid, dense settlement areas). Improve local supply of vegetable and fish produce.
3.	**EiCare**	Raise efficiency of production and marketing in extensive poultry production using dual purpose breeds. Assess potential for widespread adoption of the model.	Ethical and organic production of poultry in small-scale production units. Raise supply of organic meat and eggs for local distribution of whole chicken and eggs.
4.	**HayHeat**	Test feasible technology in specific setting of biosphere reserve. Assess benefits for nature conservation and regional sustainable development.	Use of surplus biomass for local production for the benefit of biodiversity in marginal wetlands. Improve income situation for farmers with production sites in marginal wetland areas.

Integration of sustainability aims: The focus group discussions provided for an in-depth analysis of the innovation potential related to the short term goals and the sustainability potential related to the long-term goals (Table 4). The focus group results reflect Step 3 in Figure 1.

In case study 1, for example, the microbiological system in the soils used for strawberry production is influenced by the biological control agent, but also the selection of plant material, the process of planting and harvesting will have an impact on the interactions between soil and plant. Lastly the maintenance of strawberry farms as part of the cultural landscape will influence the agricultural system at landscape level. Practical fit and potential feasibility in the local settings can be high, as in case study 1, where the work flow of planting and harvesting is hardly affected by introducing the biological control agent. They can also be very low, as in the example of HayHeat, where land ownership and property rights are affected, and new material flows between farmers and energy producers need to be created through new value chains. The characterisation of practical fit and feasibility can indicate later resistance against adoption at sector and region levels, and contribute to an early optimisation of the innovation.

Innovations that are expected to contribute to a transition to sustainable agricultural systems involve an intervention in the ecological system, often at more than one single interface. In the case of case study 1, the microbiological system is influenced by the biological control agent, but also by the selection of plant material, or the process of planting and harvesting. Each intervention, and its assessment, requires an involvement of a different set of actors.

In all four case studies, the success of the innovations was found to be largely dependent on underlying biological, managerial and technical processes that were often not understood to a sufficient degree by the individual actors. In EVI (case study 1), for example, interaction between different species of soil microbes impeded the positive effect of the biological control agent. In ASTAF Pro and EiCare (case studies 2 and 3), benchmark figures for optimal production processes were lacking at the outset of the study. In HayHeat (case study 4), the impact of grass residues on the oven material, combustion and storage were unclear. Furthermore, the extent as to what level the requirements could be influenced by field management were not clarified.

The innovation potential was, however, mainly discussed in economic terms, thereby focusing on market potentials, implementation costs, and logistics (transport, supply chains, and efficient production processes). Cost-efficiency was expected to reach a level that can compete with (case 2) or significantly differ (case 3) from other organic or conventional production systems. The sustainability potential of the innovation thus was linked to the capacity of farmers to permanently access the market by offering environmentally-friendly alternatives to existing products. Furthermore, the innovations were found to be dependent on very specific knowledge linked to the further development of decentralized agricultural production in rural and urban settings, as well as policies for resources-friendly food production and eco-efficiency (case 2, 3 and 4). The potentials for nature conservation were largely implied as a precondition, highlighting biodiversity aspects (including traditional breeds, local habitats for specific plants or conservation of wild animals), resources conservation (energy, water) and reduction of waste and surplus material.

Table 4. Estimated potential of the case study innovations

Initial Scoring	EVI	ASTAF Pro	EiCare	Hayheat
Innovation Potential				
Complexity of the innovation	⇨	⬀	⬂	⇧
Development costs	⇨	⇧	⬂	⇧
Adoption costs	⬂	⬀	⇨	⇨
Practical fit to production process	⬀	⇨	⬀	⇧
Feasibility in local setting	⬀	⇨	⬀	⬀
Sustainability Potential				
Market entry threshold	⇨	⇨	⬂	⇧
Research and development requirements	⬂	⬀	⬂	⇧
Nature conservation potential	⇧	⬀	⇨	⇨

Managing early-stage challenges in sustainability-oriented innovation processes: In the follow-up of the interviews and focus groups, we reflected on the main challenges faced by the actors involved in the innovation process. This reflection built on the summation of different perspectives provided by the Triple Helix Approach (Table 5).

Ultimately, all case studies in this research propose an innovation towards a systemic shift that can be described – in rising complexity – as a) re-organisation of production processes, b) co-operation between and merging of production processes from different agricultural sub-sectors, c) re-organisation of production and marketing by integrating existing value chains, and d) co-operation between and merging of production and marketing across different agricultural sub-sectors by re-organisation and new definition of production processes and value chains. Next to this systemic shift at different levels, four aspects ran across all four case studies. These we understood as specific to innovations that aim to contribute towards a transition to sustainability, and that require an early integration of target knowledge to facilitate the innovation process: a) the potential for directional change, b) ecosystem intervention, c) economic trade-offs, and d) impact assessment complexity. An overview on how the case study innovations relate to each of these characteristic features is illustrated in Table 5.

Table 5. Challenges faced in regard to the innovation's contribution to transitional change

Case Study		Description of the systemic shift	Potential for directional change	Ecosystem intervention	Economic trade-offs	Impact assessment complexity
1.	**EVI**	Re-organization of production by actors in one sector (production shift)	⬂	⇨	⬂	⬀
2.	**ASTAF Pro**	Re-organization of production by actors across sectors (production merge)	⇨	⇨	⇨	⬀
3.	**EiCare**	Re-organization of production and	⇨	⬀	⬀	⬀

		marketing by actors in one sector (value chain shift)				
4.	**HayHeat**	Re-organization of production and marketing by actors across sectors (value chain merge)	⬀	⬀	⬀	⇧

DISCUSSION

The comparison of the four case studies from an early stage innovation management perspective shows that the integration of sustainability into the innovation process requires an integrative approach with multiple system design factors as well as the involvement of actors with different functions in regard to the development of the innovation as well as the agricultural system and the respective value chain. In terms of management and also actor responsibility this is found particularly challenging at the front end of an innovation process (Alkemade et al. 2015). In the following we discuss the four challenges mentioned above which we find to be related to a systemic shift that is expected from the sustainability-oriented innovations in the case of success.

1. Potential for directional change

Innovations are generally assessed for their potential to contribute to directional transformation, thereby addressing the capacity of the innovative approach to achieve systemic change based on technological progress. Here, the potential for targeted disruption refers to the capacity of the innovation to challenge existing production systems, which are protected by interests, by competition between (sub-)sectors and regional entities, by lock-in effects and by economies of scale. Strong motivational drivers and incentives are required to integrate interests at strategic levels as well as in practical implementation (Nidumolu et al. 2009). The case of EiCare exemplifies how incompatibilities of the alternative production process with existing value chains lead to challenges in responsibility and ownership in regard to the innovation management. While the individual farmers generally lack the necessary risk capital to drive the innovative approach (Labarthe & Laurent 2013), third parties will calculate their risks at a very high level. Actors from research, who could potentially address questions of risk by analysis and assessment, generally see developmental activities to be out of their scope of activities. The benefits of the innovative approach can thus only be calculated at the societal level, which moves the responsibility to the policy sector. This requires the development of incentives at the governance level that widen the scope for implementation based on calculated societal benefits of the innovative approach. However, the involvement of actors was much stronger on the side of research and practice than from policy.

2. Intervention in the ecological system

All four case studies contain elements that each can lead to a positive or negative ecological impact. Farmers operate in a complex environment that is determined to an increasing extent by individual skills, local networks, cross-sector cooperation and policies defined at local, national or European decision levels. Thus, adjustments to the locality of implementation will be required in every new case of implementation, involving assessment and testing to match the innovative approach with the situation in place. Scientific analysis can improve the situational understanding as to which elements need to be maintained (Turnheim et al. 2015). Thus, the input of researchers is required not only as intermediaries in the organisation of the innovation process (Klerks & Leeuwis 2008), but plays a relevant role in conducting experimental analysis on environmental impacts. The tacit knowledge of the farmers is additionally required to adjust the innovative approaches to every single locality of implementation, where scientific analyses fall short, for example due to unavailable assessment methods. The Triple Helix approach supports the exchange of knowledge between actors to achieve a more substantiated understanding of knowledge gaps and research needs.

3. Economic trade-offs

In the context of innovation, economic trade-offs play a much larger role in the discussion than environmental trade-offs. Sustainable agricultural systems are believed to link resources conservation with economic competitiveness (Manson et al. 2016). However, the integration of activities considered sustainable is perceived to lead to delays in reaching an economic break-even. By bringing together expert knowledge from science, policy and practice, the triple-helix approach supports an exchange of information that facilitates the estimation of expected delays. Such delays can be caused by missing policy frameworks (e.g. in regard to monitoring of pests (case study 1), lock-in effects in the supply chain (case study 2), gaps in the supply chain (case study 3) or a lack of consumer appreciation for alternative production strategies (case study 3 and 4). Based on this knowledge, as well as above mentioned experimental research, the delay in reaching economic break-even can be calculated. A quantification of economic impact, even if approximate, will enable the development of (financial) measures and policy instruments to overcome risk precautions at the farm level.

4. Impact assessment complexity

Due to multi-causal ecosystem dynamics, an assessment of the impacts of change involves a high grade of uncertainty on top of the general risks in the course of proving concept, feasibility and market entrance. This seems to reduce the pull factor generally experienced in innovation processes, where consumers react to innovative approaches, and take up a new product or service. Market “push” activities, however, require additional strategic planning based on an assessment of contextual factors defined by policies, regional setting and local resources (OECD 2013). With a rising complexity of the innovative approach, the contextual factors that primarily require assessment multiply. By ensuring the participation of actors from science, policy and practice following a Triple Helix approach, we find that the identification of knowledge gaps is not only facilitated, but also easier to specify at a greater level of detail. This is found useful at an early planning stage, since options to move forward can be discussed at pinpoint, and evaluated from multiple perspectives before moving into implementation steps.

In terms of triple-helix interaction, the interaction of actors in the four case studies follows a rather unbalanced structure, with a strong representation of research and agricultural practice, but an under-representation of actors from policy – which may in effect lead to an under-representation of issues related to sustainability governance. Actors from agricultural practice in this study clearly prioritise activities needed to achieve economic success and utilisation of the innovation, thereby highlighting the adaption of the innovation to production processes and marketing channels. The under-representation of governance issues leaves actors from research with a dual role: providing knowledge for innovations and their potential impact in agricultural practice, and collecting data for estimations of innovation impact for policy actors to support a constructive policy environment.

The capacity of the described innovations to influence the agricultural system at the level of the ecosystem sets the case study innovations apart from the definition of innovations offered by OECD (2005, p. 47) which describes technological change in terms of product innovation, process innovation, marketing innovation or organisational innovation. Geels (2005) defines a separate category using the term ‘system innovation’, which includes organisational, technological and process changes, and describes systemic changes linked to agricultural and environmental systems at the level of societal functions. The case study innovations, however, involve an intervention into the ecosystem. Therefore, we propose a new category that captures the capacity of the innovation to support a transition to sustainable agricultural systems along a gradient of rising complexity on the one hand (Tidd & Bessant 2013) and the increasing number of potential interfaces for ecosystem interventions derived from the results in this study on the other (Fig. 2). We find that this advancement may further qualify sustainability-oriented system innovations with a particular impact on ecological systems. Furthermore, it may support the consideration of environmental aspects and ecological functions at an early stage of the innovation process, for example by including experimental research in the local setting of the innovation.

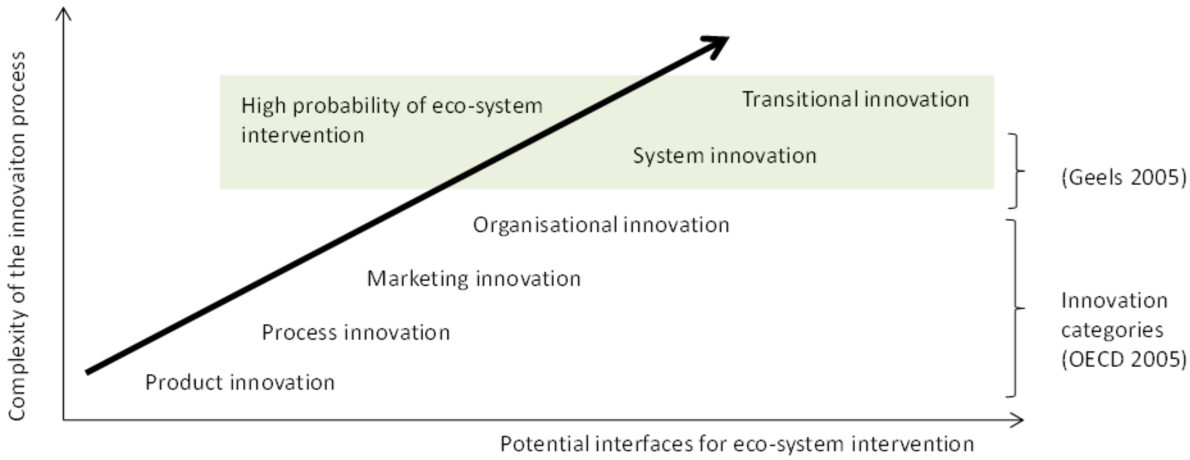

Figure 2. Rising complexity in innovation categories by potential interfaces for eco-system intervention

Conclusion

The approach used in this study was value-oriented and actor-based. The assessment criteria and methods were developed in cooperation with the actors involved in the innovation system. What was achieved was an iterative “learning assessment”, where the actors articulate what they perceive as relevant (interviews) and later reflect their activities in the innovation process against their own set of values (focus groups). The triple helix approach specifically supports the analysis of the different perspectives in relation to development potentials, and can be in principal enhanced to include sustainability considerations.

Much literature concerned with front end innovation is linked to the context of achieving market entrance. With agriculture being highly dependent on natural resources as well as on skills and abilities, systemic foresight processes at the front end of innovation development need to take a broader approach. An integration of sustainability issues in early planning can improve actors knowledge of potentials and risks particularly related to ecosystem intervention, and thus highlight the need for additional activities needed to optimise the allocation of resources as well as accelerate the innovation process (e.g. via complementary experimental research). While the assessment of cross-cutting challenges was conducted as a desk-top assessment, in principle, front end activities should involve a participatory reflection of all actors on a) the potential for directional change, b) ecosystem intervention, c) economic trade-offs, and d) impact assessment complexity. This would support the formulation of required steps to take in innovation development in regard to sustainability aims, and clarify the allocation of responsibilities between actor groups.

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