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Identifying System-Related Barriers for the Development and Implementation of Eco-Innovation in the German Horticultural Sector

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Abstract: The implementation of eco-innovations can be a strategy to combine economic benefit and reduce negative environmental impact. German greenhouse production is highly energy intensive, as heating and energy account for the second largest cost factor. Thus, the sector wants to develop and implement eco-innovations to speed up the process towards increased sustainability. In this paper, a sectoral systems of innovation (SSI) analysis is presented to identify and describe interrelated systemic barriers for developing and implementing such innovations into the sector. The SSI was used as an analytical framework, which enabled covering different system levels and components in the research in order to draw a comprehensive picture of this specific innovation environment. A mixed-methods, explorative approach was used: a literature analysis, followed by an expert workshop and semi-structured expert interviews, was conducted to understand the barriers for development and implementation of such innovations. A SWOT workshop assisted in generalizing results from selected innovation examples. A complementary two-wave Delphi study was used to identify innovation activity, important actors, policies and drivers within horticulture. Based on these data, we were able to identify different barrier-types, showing how they are interconnected and affect innovation processes increasing ecological modernization of the sector.

Keywords: sectoral systems of innovation; ecological modernization; energy efficiency; barrier types; co-innovation

1. Introduction

The agricultural and food sector is a major emitter of greenhouse gases, but also exhibits great potential for developing transformative solutions and strategies to reduce such emissions, which contribute to global climate goals or the sustainable development goals (SDGs) [1]. The highly energy intensive production of foods and ornamental plants in horticultural greenhouse production potentially plays a role in the development of adaptation and efficiency strategies—specifically, in temperate zones such as Germany. To date, climate change and adaptation reporting for land use and agriculture often neglects this specialized agricultural subsector as shown by the Intergovernmental Panel on Climate Change (IPCC) [2].

Achieving the optimum use of energy plays a major role for long-term profitability and competitiveness of the horticultural sector and its enterprises, but also for increased sustainability. In 2018, 80% of energy used in greenhouses was still based on coal, gas, oil fuel, heavy oils, wood, long-distance heating and electricity, while 20% was covered by renewable energy sources (wood, biogas and plant-based oils) [3] (p. 32). Additionally, small and medium-sized enterprises (SME) that are characteristic of this sector still often use old facilities and equipment [4]. This type of enterprise has been found to be less energy-effective than larger enterprises and is, thus, the focus for policies addressing national climate and sustainability goals [5–8]. These policies are designed to foster eco-innovation and thereby promote overall ecological modernization (EM) [9–12] through regulation, legislation, tax incentives or incentive grants [6,10,13] or change of discourse [12]. In the last decade, Germany has introduced several sector-specific programs that should spur innovation activity in horticulture and agriculture, increase development and implementation of eco-innovations [14] in general, and energy efficient technology specifically [7]. These programs are also meant to stimulate added services such as energy consulting or knowledge transfer [7], while others are directed at increased traceability of products and consumer protection [15–17]. The introduction of eco-innovations intends to reduce negative environmental externalities and can possibly drive down operating costs in a sector that is characterized by heterogeneity and has experienced structural change and rationalization during the past 25 years [8,17,18]. Reducing emissions and using energy efficient technology, energy management practices or meeting increased consumer expectations could potentially make horticultural businesses more competitive, but would also contribute to national and global climate objectives, which is a major challenge for horticultural and agricultural value chains [19–26]. However, EM is a multi-faceted process that includes organizational, societal, market or ecological considerations, subsuming different types of innovation such as techniques, practices, processes or services [10,11]. Thus, it still faces implementation barriers at several system levels [25–27]. The lack of adoption of energy efficiency measures specifically (and related management activities) is also framed as the energy efficiency gap [28]. In order to address this mismatch, scholars from different disciplines have sought to identify and classify barriers that prevent such innovations from being developed, adopted and diffused [29]. This body of literature includes perspectives on different sectors, sub-sectors or single enterprises [20,24,30–33], focusing on economic, socio-economic or political aspects. However, the literature argues that barriers are still often analyzed and addressed separately [12] and their interconnectedness is not sufficiently investigated. In order to address this interconnectedness between different sector specific barrier types, a systems approach is required [12,34]. To date, the sector has often been studied from single technology-based perspectives, e.g., for insulation, light-emitting diodes (LEDs) [35], mix of green fuels, greenhouse architecture, breeding [36] or labeling and consumer protection [17]. Other studies focused on the intention behavior gap at the managerial level regarding the adoption of energy-efficient technologies in horticultural businesses [37]. Still, work on revealing the linkages between single barriers and barrier types, as well as cross-linkages between actors in the value chain has remained largely undone.

Thus, in this contribution, we adopted a systems approach to describe the innovation environment relevant for eco-innovation conducting a nation-wide sector analysis [33]. We identified system-related barriers that impede the development and implementation of eco-innovation in the sector. By outlining how these barriers interconnect we were able to present conclusions on how these barriers can be addressed. Additionally, we looked for mechanisms that help to further promote eco-innovations such as co-innovation activity [38]. To do so, the research applies a mixed-methods, explorative approach that connects three system levels that interact in this multidimensional system: the sector (horticulture), innovation field (eco-innovations) and single innovations (innovation examples). Adopting this broader systems perspective also offers the possibility of identifying change or adjustment initiated as new technology, legislation or management are implemented and diffused [39]. For its analytical framework, a sectoral system of innovation (SSI) approach was applied [40,41]. As much as these frameworks are powerful tools for *describing* system arrangements, they have limitations in terms of *explaining* the processual, dynamic, interconnected character that is inherent to innovation [42–44], while they can also overlook activities of individual actors [39]. An explorative approach supported the gradual generation of results across the three system levels and allowed triangulation of results for a final picture of the innovation system. First, a pre-screening of sector literature provided orientation in the research field and provided first insights into system structure (e.g., relevant players, key sector figures). This information was used to conceptualize an initial expert workshop aiming to identify a paradigmatic, sector-relevant innovation field that the in-depth study should focus on. Thereafter, expert interviews in the selected innovation field were conducted using exemplary IPs (e.g., use of alternative fuels, thermal shields or CO_2 footprinting) to disclose system mechanisms and barriers. Afterwards, a SWOT (Strengths-Weaknesses-Opportunities-Threats)-workshop was conducted with stakeholders to validate and generalize the innovation-specific results from the case study to the sector level, which enabled making qualitative concluding recommendations. In parallel, a complementary nationwide, two-wave Delphi survey on sector level assisted in identifying innovation activity, important actors, roles, policies, trends and drivers.

In the remainder of the paper, we first situate the contribution in a wider theoretical discourse, then move on to description of the reference framework that was used to structure the empirical work and the presentation of results. Based on the systems analysis, we outline how different barrier types are systematically connected. Finally, it will be shown how specific parts of the sector have developed further recently.

2. Theoretical Background

Eco-innovations aim to combine economic benefit and reduction of negative externalities regarding the environment [10]. Such innovations are often conceptualized as process innovation, as they most likely require more than the implementation of a new technology, but require rather a deliberate management throughout the innovation process (IP) [12] as they initiate change in the innovation system [42]. Eco-innovations are defined as the 'implementation of a product that has environmentally positive effects [. . .] this includes end-of-pipe innovation as well as substitution of material flows in the life cycle of products' [10] (p. 16). Beise and Rennings added that eco-innovations are 'new or modified processes, techniques, practices, systems and products' [43] (p. 8). Thus, these innovations address the environmental and social dimension [14], but may strongly be motivated by economic aspects such as reducing costs or better product quality [43], which is realized in the development of goods and services that might increase eco-efficiency, the reorganization of structures and processes, the implementation of new forms of management or the development of new products [10,12,14]. In a related discussion in the German horticultural sector, 'eco-innovation' is rarely used as a term; instead, 'energy efficiency' is applied interchangeably and is widely established as the predominant concept. It is used in national policy programs and by other authorities, e.g., [7], but is also applied in European scientific literature [20,24]. Many eco-innovations that are developed in the horticultural sector in Germany are in fact related to energy efficiency. The term energy efficiency subsumes the same variety of innovation types as eco-innovation, e.g., strategies of substitution, energy management or energy consulting [7]. These two terms connect to the overarching policy concept of EM [12], which is designed to increase sustainability by modernization. In this contribution, we refer to this literature with regard to higher-level processes aiming to perform a transition of discourses, practices and technologies and institutions towards a 'greener industrial society' [ibid.] (p. 416).

Development and implementation of eco-innovations are complex, long-term processes that potentially alter mechanisms in IPs. Thus, they should be deeply integrated in enterprise's business strategies to establish principles of action. Additionally, such process innovations typically assume that actors must navigate in multi-level, multi-actor settings [44], working together with actors that they were not working with before, as in co-innovation [38]. Co-innovation requires iterative, contextualized and tailored coordination of IPs [ibid.]. These requirements play out as an enormous operational challenge for SMEs that have only little resources available; quite typical for the German horticultural sector. Thus, increased strategic and systematic implementation and diffusion of eco-innovation or energy-efficient measures still faces systemic barriers, delaying EM [10]. Accordingly, there are different gradations of strategic embedding of sustainability aspects into enterprises, moving in a continuum between resistant, reactive, anticipatory, innovation based to sustainability rooted [14]. Along similar lines, Schot and Steinmueller described how innovation policy addresses these challenges at a higher system level as an evolutionary process [45]. They discuss to which extent policy already manages to create supportive conditions to better connect sustainability and innovation objectives, thus providing increased directionality to enterprises; allowing to reduce uncertainty in turn. Education and training of entrepreneurs are identified as barriers that need to be tackled to increase absorptive capacity and innovation activity, to allow enterprises to consider sustainability as a core issue in their innovation activity. For this to happen, the environmental and the social discourse need to be aligned more proactively with innovation objectives in a long-term process [45,46] (p. 1561). Sorell [29] distinguished pragmatic barrier types (e.g., economic, behavioral or organization) for involved actors, which negatively influence this process. However, to date, barriers are too often analyzed and addressed separately [12] and their interconnectedness is not sufficiently investigated and described. A systemic approach would be needed to address these challenges. Therefore, an SSI approach is used as an analytical tool to structure the research and unpack the configurations and interactions of the system, rather than to assess system performance. We would like to understand systems of innovation as *configurations of organizations concerned with generation and utilization of scientific and technological knowledge* [45] (p. 1558). The SSI framework as introduced by Malerba [40] was used here because its associated components and system levels provide a structure for analysis and offer a multidimensional integrated view [40,41]. At the same time, the design of the approach allows for adaptation. The components included in the approach are briefly described: (1) *Technology and demand* identify technologies and trends, as well as the demand situation particularly geared towards evaluating what innovative solutions can contribute to an EM of the sector. (2) *Competition* should outline the situation in the sector within both national and international contexts. In this regard, it is argued that future competition will be among value chains rather than among single actors and nations [47]. (3) *Institutions and politics* are concerned with policy and legislation that mainly influence the sector (e.g., specific departmental policies). (4) *Agents and organizations* describe characteristics of existing organizations and actors, e.g., individuals or groups, enterprises, universities, financial institutions or local authorities that are relevant for the implementation of innovations. (5) *Interactions and intermediaries* include market and non-market relations and communication between actors. (6) *Knowledge base and human capital* defines sector-specific and cross-sectoral knowledge processes and learning mechanisms needed to implement innovative solutions. By applying these components as a major structure, the system can be described. Nevertheless, in order to explain how the components are interconnected and together play out as enablers or barriers an additional element, (7) *innovation processes*, was added [33]. This takes into account the often-overlooked processual and dynamic character of innovations e.g., [48,49].

3. Materials and Methods

There are typical methodological difficulties and limitations that arise when studying innovation systems and IPs, such as identifying appropriate levels of analysis, defining system boundaries [50,51] or handling the processual, dynamic character of systems [48]. To address this, an iterative research design [52] that uses five methodological steps that chronologically build on each other was developed. This allows to navigate the empirical research on three different system levels using interim and final triangulation steps, thereby moving from general to specific and back (Figure 1). After each step results were analyzed and used to improve the design of subsequent steps [53]. The evidence obtained from single steps were presented in next empirical steps, e.g., during interviews and workshops as well as in scientific workshops and conferences. This assisted in making the data collection process transparent and validate the interim results as well as the methodological approach [54]. The different methods used were needed to gain insights in the complex nature of eco- innovation processes in horticulture; but also provide what Goffin et al. [54] call substantiation for the generalization of results. The collection of empirical data took place between 2011 and 2013, and further processing of the data was done subsequently. The sector development was irregularly observed until 2019, e.g., during participatory observation of two workshops addressing innovation topics in the field of horticulture (2016 and 2018). These mixed methods approach finally provided an enhanced and more holistic understanding of the system. The contribution evolves from a multiple-case study project exploring the SSI of the German agricultural sector, covering animal production, plant production [33,55] and horticulture [56].

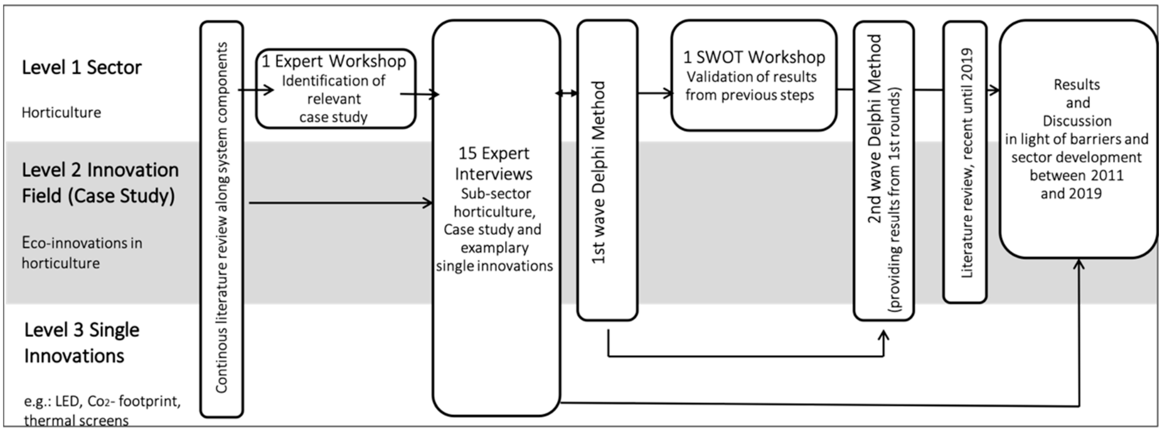

Figure 1. Research design (own figure based on [33]).

The methods are described in the following according to their function in the research process:

Literature and document analysis had three functions in the research process: *Initially,* literature covering SSI studies in the fields of horticulture and agriculture was screened to identify pressing issues in the field and to develop a theoretical sampling strategy for case study selection leading to the following selection criteria: system relevance (regarding technical and social trends concerning the environment and resources), contribution to sector competitiveness (exploring niches, increasing efficiency, exploring new markets), relevance regarding added value (networking with adjacent sectors, suppliers, employment) and focus of IP in Germany. This assisted to identify and pre-select possible case studies, as well as to prepare a pilot study [54]. *Later in the process*, relevant scientific literature covering SSI studies in the fields of agriculture and horticulture was analyzed with regard to the selected case study. Keywords used in search data bases such as science direct were e.g., 'energy,' 'energy-efficiency,' 'eco innovation in horticulture' and 'barriers for development and implementation of eco-innovation.' Sector statistics (structural data, national statistics) and policy documents funding schemes (ministries, administration) were assigned to the components of the reference framework. Relevant documents were constantly reviewed under the study period 2011–2013 to monitor system development, and afterwards at irregular intervals until 2019 (e.g., through follow up of research projects websites, policy programs and sector statistics). *Then*, scientific literature from the fields of innovation research, EM and eco-innovation was used to situate and connect the contribution to the wider theory discourse.

Pilot interviews and expert workshop for case study selection. Based on the literature and document analysis, a pilot study [54] was conducted to further refine the methodological approach and to assist preselection of the case study fulfilling the developed selection criteria, as the case study was not predefined. The suggestions were discussed in an externally moderated expert workshop. Participating experts were identified based on the preliminary literature analysis and on first explorative interviews under the pilot study [57], due to their expertise in the field and representation of different system levels or value chain steps. Selection followed the principle of purposive sampling [58] (p. 85), meaning a targeted deliberate selection of the sample based on the insights gained in the literature and document analysis, article authorships or recommendation by interview partners. Finally, 25 experts participated in the workshop representing: horticultural practitioners, ministry of agriculture, administration, finance, industry, associations, science, extension and suppliers. Representatives from professional training, organic horticulture and consumers, were missing from the workshops due to unavailability. In a moderated group discussion, the case study suggestions were further refined applying the developed criteria. The discussion was visualized, protocolled, iterated and approved among participants subsequently. Results are publicly available in a report [33] (pp. 312–316).

In-depth case study: In a next step, 15 semi-structured *expert interviews* [59–61] were conducted with experts who either had insights into specific eco-innovation examples (e.g., LEDs, temperature-optimized breeding, CO_2 footprinting, thermal screens and substitution strategies), or had profound system knowledge. Again, experts were defined according to [57] and selected through purposive sampling. Experts should represent different positions and functions in the value chain to be able to cover most system functions. The interviews were thematically structured along the system components and had two parts: part one specifically focused eco-innovations in horticulture. Here, interviewees were asked to describe specific IPs in further detail if possible. Part two was dedicated to more general system conditions for the implementation of eco-innovations. This included general sector specifics, specifics of the sector's IPs compared with other sectors, and the main sector challenges. An overview of the number of experts per group is given in Table 1.

Table 1. Interviewed expert groups and their fields of competence.

Expert Groups	Interviews per Group	Core Competences of Experts per Group
Intermediate organizations and politics	4	General political frameworks related to eco-innovations, coordination and networking across institutions
Horticultural enterprises/practitioners	3	Exemplary innovation: breeding, LED lighting, thermal screens, practice-science cooperation
Supplier industries	2	Building cross-sectoral networks
University and non-university research institutions	3	Characteristics of IPs in the sector, mechanisms in science-practice collaboration
Labeling and certification	1	Labeling (e.g., CO_2) in Germany compared with other countries
Extension services and energy contracting	2	Role of extension in horticulture, networking and pooling of energy.

The interviews, which had a duration of 1–2 h, were recorded and transcribed. The transcripts were processed using MAXQDA [60], a software to analyze qualitative data. A structured content analysis [58] (p. 111) was done applying the system components of the reference framework as initial categories for deductive analysis. These could subsequently be used for inductive identification of categories and sub-categories. In two subsequent rounds the number of categories was finalized. Eleven main categories (*agents and organization, policy and institutions, interaction and intermediaries, competition, knowledge base and human capital, technology and demand, specifics of horticultural IPs, innovation types, obstacles and supportive factors, typical IPs and innovation trends*) and 41 subcategories were generated in this process (see Table S1, Supplementary Materials). The most mentions could be assigned to the category 'supporting and hindering factors' (89); the least to 'competition' (10). Finally, the statements from single interviews within the same category could be compared for generation of category-based results. The co-authors gathered regularly in-depth interim discussions during all steps of the study for a coherent approach and for promoting reflexivity and dialogue to allow for consistent structure of the content analysis [62], which supported insights on specifics in horticulture in comparison to two parallel case studies [55,63]. Triangulation was additionally supported by joint (interim) report writing.

Explorative quantification and generalization of selected qualitative findings: A Delphi survey was conducted using an identical sample of experts at two points in time of the study. A standardized questionnaire, the anonymity of individual responses, the assessment of statistical group response and the provision of feedback information on statistical group response to participants prior to repetition are typical for this method [64]. The purpose was to produce additional system knowledge on sector level with regard to system components adding information to interviews. Conducted nationwide, it exploited the expertise of participants who were chosen using purposive sampling, amplified by recommendations from interviewed experts. The questionnaire comprised 14 questions, harnessing experts' experience with regard to: actors or actor groups for initiating innovation, obstacles and main success factors for IPs, main sector challenges, impact of different legislation on innovation activity in the sector, development and qualification of workforce, and technological and social trends in the field. In the second wave, the sample group was provided with results from the first wave they were asked to repeat the questionnaire. Delphi surveys have previously been used to assess trends and impacts in the field of agriculture [64], as the method helps to obtain a quite reliable consensus of opinions from a group of experts [65,66]. Moreover, potentially biasing effects of dominant individuals can be reduced. Optimal size and scope of Delphi groups are rather dependent on the main target and resources available [67] and a larger number of participants may not automatically lead to better results, as quality is rather influenced by the structure and balance of the sample [ibid]. In this study, the response rate of questionnaires was sufficient to obtain a usable result: 18 of 51 surveys were returned in the first wave (Delphi 1) and 24 in the second (Delphi 2) (see Table 2), reflecting a response rate of 35% and 47%, respectively. Thus, some experts that had not answered in the first round, did so in the second. Due to anonymous feedback, these additional returns could not be traced. The data from both waves were statistically analyzed in excel and are available as excel charts.

Table 2. Sampling of invited experts for Delphi rounds 1 and 2.

Groups of Experts Invited for Delphi 1 and 2	Number of Experts per Group
Production (organic and conventional)	7
Supplier industries (incl. public services, excluding extension)	9
Services (e.g., financing)	3
Extension services	6
Science	11
Intermediate organizations (media, associations organic and conventional)	9
Political institutions and administration	1
Others (e.g., retail, marketing, cooperatives)	3
Producer organizations	2
Total	**51**

Validation and discussion of findings: The *SWOT workshop*, which took place in between Delphi 1 and 2, was used to set the very detailed results from Levels 2 (innovation field) and 3 (single innovation) into a wider systemic context (see Figure 1). The results were shortly presented in a key message fashion and participants were to choose two out of seven key messages for further discussion. *Interface management to improve communication and coordination among innovating actors* and *role of extension services for creation and diffusion of eco-innovation* were chosen as most relevant issues. In a session led by an experienced external moderation these two issues were discussed. In order to gain balanced results, 25 experts from the sub-sector were invited and finally; six experts representing different value-chain steps attended. The discussion was visualized, and the results were iterated and approved in a written protocol and as a photo-protocol afterwards. All interim results from operationalization decisions, workshop protocols, document analysis results and Delphi survey were transparently documented and are publicly available [33] (pp. 301–422).

4. Results

This section jointly presents results from interviews and Delphi as well as the SWOT workshop. The results are substantiated and contextualized by relevant sector literature. The section is structured in seven paragraphs along the components of the reference framework starting with background information that should assist to further contextualize the empirical results.

4.1. Sectoral Background

The German horticultural sector faces several challenges [8,19,20], including the need to reduce the amount of fossil fuels for energy and heating in greenhouse production or compliance with increasing consumer demands. As of now, heating for greenhouses accounts for 2647.7 Gwh, of which 28% is from black coal, 21% from natural gas and 15% from fuel oil; renewable sources make up for appr. 20% [3]. In order to remain competitive compared with geographically more advantaged regions such as Spain, Germany has to drive down energy costs and energy consumption in horticultural production. To date, more than 90% of costs for energy in greenhouses are used for heating systems, which might account for up to 10% of annual turnover [24]. Similar figures are reported for the Netherlands [20]. However, much lower figures are reported from Spain (3%) [68]. In order to comply with national climate and sustainability goals, the national cross-sectoral energy efficiency program (NAPE) was framed for the agricultural and horticultural sector [7] to support energy-efficiency measures and reduce energy use including extension, knowledge transfer and the implementation of energy-efficient technology as key areas.

A major challenge is the progressing structural change: in 2016, there were 3813 hectares of protected horticulture in Germany [3]. As the number of horticultural businesses is decreasing, firm size is increasing: between 1995 and 2016, the total number of horticultural businesses declined by almost 50% (from 53,000 to 27,000) [ibid.]. Despite these developments the sector exhibits a high degree of heterogeneity, showing a strong degree of product specializations, ranging from various kinds of potted plants to highly specialized vegetable varieties. Additionally, costs for labor and increasing consumer demands (e.g., sustainably produced, traceable) pose major threats. Potential innovations to address these challenges include combined use of alternative fuels, thermal screens to avoid heat transmission losses or climate control systems, implementation of social standards regarding GHG emissions, strategic alliances for fuel purchase or energy contracting, sensor technologies or LEDs. The tensed situation and competition in the sector do not yet allow for strategic embedding of sustainability issues [14] as a principal strategy into enterprises. Taking these figures as a background information, we will show why enterprises are more often able to implement single innovations that are not linked systematically, rather than a 'whole package' (SWOT workshop) of innovation activity that is linked more consistently across the value chain.

4.2. Which Are Relevant 'Technologies,' and Are Enterprises Able to Articulate Their Demand?

Asked about potential innovations for the sector, experts mentioned mainly efficiency or substitution strategies, often related to technical innovations, such as roof coverings, climate computers, heating systems adopted for the use of alternative fuels (thermal energy, solar energy, etc.), sensor systems and regulation systems such as thermal screens or LED lighting systems. In a production segment that needs about 90% of energy for heating systems [24], this plays out as an economic barrier compared with climatically more advantaged regions such as Spain. Saving potentials of these single measures varies, depending on how well the technology is adapted to the enterprises' specific situation: thermal screens have a savings potential between 20–40%, sealing and ventilation 10–20%, heating systems 10–18% and climate control 10–20%, whereas isolation measures can save up to 10% [68,69]. However, for various reasons, horticultural businesses, which are the users of such innovations, sometimes have serious problems to formulate their specific demand to industry partners (Interview, 13, scientist univ.). One reason is imperfect information about the applications of certain technologies in their own business, which often come from other application fields or branches (e.g., machinery, sensor techniques, Interview 13 and 9, producers association). Consequently, horticultural enterprises sometimes use technologies that have not (yet) been adjusted to the sector or the specific need of one enterprise and therefore might not consider sector-specific characteristics (Interview 9, producer association). This may lead to unsatisfactory results and impedes future innovation activity. A major reason here is missing comprehensive situational analysis in enterprises regarding energy consumption, or performance of technology on site (Interviews 13, 14 scientists univ.; 15 expert R&D). This missing knowledge hinders a clear formulation of the demand, and thus, influences possibility to receive an appropriate solution. Recently, specifically trained energy advisors should assist enterprises to improve this situation (see also Sections 4.4, 4.6 and 4.7). Furthermore, the large variety of possible innovations in the field of energy innovations is a challenge that has not yet been met: the results from the SWOT workshop [33] show that existing extension services are not able to cover the full width of possibilities, causing a relative degree of uncertainty concerning the possible impacts of innovations for individual enterprises.

Other types of innovation mentioned addressed the increased consumer expectations including traceability systems or ecological footprinting for horticultural products. However, such innovations are not yet being significantly requested by producers, as they tend to increase complexity in production processes that cannot always be incorporated into daily workflows. Additionally, producers stated that costs involved cannot easily be passed on to the consumers (Interview 11, expert on labeling). The growers demand innovations that have a convenient level of usability along with an acceptable price. Moreover, the innovation's advantage for their own business is a key focus in their decision process. Nonetheless, there is evidence that debates on the consumer side have been taking up this topic more frequently during recent years, which is a development to which producers will have to react [3]. Other countries such as Great Britain were mentioned to have made more efforts in labeling, e.g., through the Carbon Trust (Interview 11, expert labeling). Overall, despite ambitious goals at the EU level regarding traceability and carbon footprinting, innovations concerning product-specific carbon footprints in the sector are not ready yet to be widely applied in practice (interview 15, scientist). Summing up, in the absence of a comprehensive overview at enterprise level, a concrete strategic vision for the sector is not easy to make. Efforts are still rather focused on single strategies or technologies; a coherent technological paradigm could not be identified by this research.

4.3. What Is the Competitive Situation of Germay's Horticultural Sector Compared to Other Regions?

Experts stated that questions regarding the competitive situation are hard to assess and they were only able to give general statements (Interview 1 member association; Interview 4 practitioner, and Interview 15 horticultural scientists). However, the assessment was that due to sector conditions (e.g., disadvantaged climate or development of fuel prices), Germany has a high incentive to be competitive in terms of technical innovations (substitution strategies, innovation to increase energy efficiency), despite the small overall impact of the agricultural sector for the German economy. As other sectors also have to comply with national requirements, horticulture can partly benefit of the progress that other sectors have already made and from which they can contribute e.g., technical solutions. The main future threats for competitiveness German horticultural businesses would appear to be the increasing costs of energy and labor, as well as structural change (Interview 1 association, two policy/administrations). Due to statutory requirements, Germany previously had the possibility to hire more affordable seasonal workers; however, currently, minimum wage is enforced in the sector. Additionally, spurred by societal discourse, requirements concerning traceability and quality are steadily growing—increasing the costs of such products, which might trigger increased innovation activity (Interview 11, expert labeling). Here, other countries (e.g., France, Switzerland and the UK) were mentioned to have engaged already more strategically in research, and initiated proactive implementation into retail. In those countries, the impetus has come from governments and supermarkets or arised from societal discourse. Having policy directionality and incentives, producers are then encouraged to implement the resulting directives.

With their horticultural cluster, The Netherlands is among the most serious competitors in terms of energy-saving strategies and technologies in horticulture (reducing costs) but also with regard to labeling and other eco-innovation (considering higher consumer demands). The greater importance of agriculture and horticulture for the country's overall economic performance, however, supports innovation activity. In conclusion, the SME structure of suppliers and manufactures in Germany that is concentrated and specialized mainly in the domestic market increases price pressure and play out as serious barriers for implementation of eco-innovations.

4.4. Which Institutions and Politics Are in Place to Support Eco-Innovations in the Horticultural Sector?

Much has changed here during the last years: a follow up of policy programs between 2011 and 2019 showed that policy increasingly aims to support sustainability behavior and innovation activity in enterprises, sectors and among consumers. This was done progressively by translating national strategies into specific sector strategies [7,13,70,71]. The national action plan on energy efficiency (NAPE) is one example where it was translated into the 'energy efficiency program agriculture and horticulture' and provides a framework for the sector to develop and implement eco-innovation [6]. However, legal requirements may also encourage path dependency in horticultural businesses to an extent, specifically under circumstances of missing directionality or discontinuity of legislation (Interviews 1 and 14, association member and scientist). This contemporary innovation policy still needs to take greater account of structural specifics of the sector (ibid and SWOT workshop). Furthermore, the design of frameworks and funding guidelines need to consider dynamics and interaction in IPs [72,73] to a greater extent. Flexibility in funding schemes would be needed to take account of the important characteristics of Ips, such as large number of actors or unpredictable and iterative processes. Based on results from the Delphi study, Figure 2 shows where in the IP problems are most likely to occur.

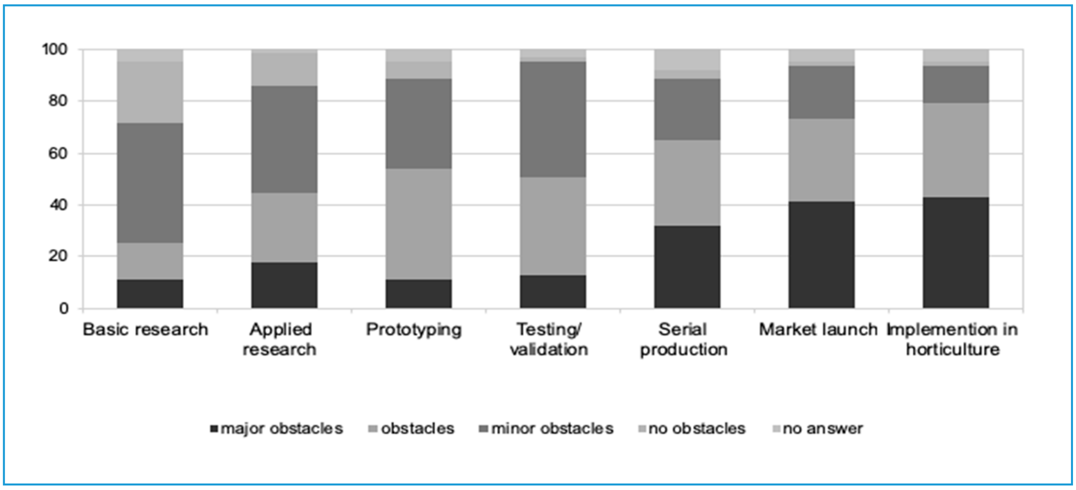

Figure 2. Barriers throughout the IP (Delphi 2. n = 24, frequency in %) own Figure based on [33].

There was a general consensus that fewer problems occur at the beginning of an IP, as funding is often provided for basic and applied research. This is quite opposite to later stages of the process, starting from prototyping and spanning to implementation. As there are some funding schemes that consider the later stages, actors are reluctant to apply to such programs as the requirements might be incompatible with daily routines. Furthermore, sector specifics and heterogeneity are inadequately addressed, in a sense that continuity and flexibility are lacking, representing a contrast to the necessity of long-term planning for businesses. Lastly, regional and national programs may sometimes inhibit one another or change to the disadvantage of specific target groups. One example is the renewable energies act (EEG), which is no longer attractive for horticultural businesses in its newest amendments.

However, during the empirical phase of this study it was assessed as rather positively influencing the implementation of energy efficiency innovations (Delphi 1 and 2).

Overall, actors express the need for policy to target also soft barriers, such as achieving cooperation between actors who have not been working together before, while also addressing communication barriers. This would be a necessary precondition for co-innovation processes, which are needed in horticulture, as innovations often originate from other sectors as previously shown.

4.5. Which Are the Central Actors and Organizations and Which Role Do They Take in the IP?

Three central actor groups involved in IPs related to eco-innovations were identified. First to mention are public and non-public research institutions (all interviews). However, the focus of research activities undertaken was mentioned to not yet sufficiently address the requirements and needs of producers or consumers, as collaboration between these two was described as partially lacking and difficult (Interviews 3 and 7, scientist breeding and representative breeding company). This mismatch was explained to be due to the pressure to publish in peer reviewed journals and the neglect to publish in more practice-related magazines. This creates major obstacles for communication and engagement between science and practice (Interview 2, policy/administration). A second key actor is the extension service, which plays a major role and is meant to act as a key translator between practice and science. However, some experts argued that extensionists have not fully 'understood' and taken this role yet (SWOT workshop). Established in the 1960s, the German extension service has undergone massive restructuring from publicly funded to a more private system (Interview 4, association). This situation affects all actors in the system and leads to structural and economic barriers, regarding the implementation of eco-innovation and energy-efficient technology in particular. Actors hope for a better and more specialized extension service that can assist in embedding sustainability aspects more strategically in their enterprises (SWOT workshop). However, even more importantly, the lack of extensionists focusing energy aspects must be considered a major bottleneck for the diffusion and adoption of such innovations into horticultural practice. Until recent, energy consulting was undertaken by experts from other sectors, such as facility management, whereby such experts were often not familiar with the specific conditions in horticulture (e.g., special requirements of breeds). However, with the introduction of sector specific policy programs, certified energy advisers are starting to be funded. Even if these developments show first results, these offers need to be implemented more systematically.

The growers take a specific role within IPs related to eco-innovation: results provided the insight that their role is a rather passive one, as they clearly see themselves as 'users' of innovations (12 mentions in Delphi). In contrast, their relevance as 'innovative entrepreneurs' is rather low (two mentions in Delphi). This assessment was also confirmed in interviews with regard to the examples of efficient light sources, LEDs and breeding for heat tolerance (Interviews 3, 7 scientist breeding and representative breeding company). One interviewee said: *"we have nothing to do with innovations, we're being judged on how much we produce; not on how innovative we are"* (interview 9, horticultural producer). The growers' role as 'tinkerers' or 'innovative entrepreneurs' was less developed. This has implications for organization, iteration and management of feedback loops as well as interaction and communication routines in horticultural IPs; for example, in cases where co-innovation would be useful. Quite the contrary, representatives from science stated that they believe the function of growers in IPs mainly lies in initiating and giving impetus to innovations (Interview 14, scientist). Finally, this different understanding of responsibilities in the IP may lead to false expectations, and it is likely to affect the ways in which actor groups are willing to involve themselves in IPs with other stakeholders (SWOT workshop). This misunderstanding is also likely to cause problems in information flows, learning processes and increase the number of feedback loops necessary in IPs.

4.6. Which Role Do Intermediates Play and How Do They Interact with Others?

The interaction between the actors in the system was discussed intensively in the expert interviews, but mainly during the SWOT workshop during validation of results. One of its most important dimensions relates to the changing roles and functions of actors over time within the IPs (SWOT workshop). For example, the role of extension spans from consulting to coordination and management IPs (Interviews 1, 14, association member and scientist). These new roles might also include closer cooperation with consumers and society in the development of products, increasing collaboration and feedback loops in IPs. There is also vast acknowledgment of these facts in the literature [72–74]. An often-discussed matter in this respect was the role of extension services as translators, facilitators and major intermediaries, brokers or boundary spanners. It is well understood that effectiveness has recently decreased due to changes in the extension services structure and financing (results SWOT and Interviews). Nevertheless, intermediaries are expected to function as translators between the actors in the system (mainly growers and scientific researchers) and actors outside the system boundaries (suppliers, related industries) in cross organizational IPs. However, due to the aforementioned problems, extension is unable to organize feedback loops and interaction processes in the IPs in the ways expected by other system actors (SWOT Workshop).

Another major issue mentioned was that extensionists know only a part of the system, and cannot be 'all-rounders' (SWOT workshop). Access to independent information was mentioned crucial—which can only be granted if extension services are strictly separated from selling activities. During SWOT, experts assessed that there is only a small chance that the system will be adequately supported further. It is more likely that new mechanisms and solutions need to be developed and that the extensionist's role has to be redefined or other actors need to come into play. Finally, the horticultural sector is a sector that is well connected and is based on networks and personal relationships. However, parts of the sector are very traditional and tends to lock-out new actors. Institutionalized intermediates exist, who aim to improve connections within the sector, although they specialize in specific actor groups and leave out other relevant actors.

4.7. How Can Knowledge Help to Further Speed up Innovative Activity?

Many technological innovations used are developed in adjacent sector such as textile industries or senor technology. Therefore, knowledge and expertise from outside the sector is extremely valuable, and joint learning processes, e.g., in co-innovation processes, are desirable. However, transaction costs to find possible partners in the development of energy efficient innovation were mentioned to be high (Interview 13, university scientist). Additionally, knowledge on how to organize and coordinate learning processes within IPs is rare (Interviews 9, 14 extensionist and scientist). In fact, interviewed experts had difficulties specifying were in the knowledge process major obstacles occur and how they could be addressed. It was stated that there is a research gap regarding different components that are needed to design a successful knowledge base. Moreover, the data situation at all levels need to be improved to facilitate strategic development and vision-building in the sector. With sufficient data, changing conditions could be better made visible and needs could be addressed.

Regarding the energy case, there is evidence that universities or private and public research institutes are the most significant producers of knowledge (Interview 14). Nevertheless, these efforts are mainly reflected in scientific publications, as knowledge and technology transfer play a minor role in academic incentive systems. Cross-sectoral and inter-sectoral knowledge is mainly imparted at conferences, exhibitions and trade fairs. Based on this situation, communication with other branches, such as machinery, sensor technologies (e.g., for cooling systems), electronics (LED lighting systems) or the textile industry (heat shields), still has to be enhanced. A serious obstacle here is data availability and specific formulation of demands (see above). In order to provide consistent exchange of data, communication and interaction rules and routines need to be further improved. A possible approach could include improving interface management (SWOT workshop, interviews). However, sufficient and sustainable (exceeding specific project) joint learning processes in the triangle of science practice and extension could not be detected by our research.

On a more organizational dimension, there is a need to deal with a lack of successors who wish to take over family business and bring new knowledge into the businesses, this debate is also related to structural change. Although the complexity of innovation requires skilled and highly-qualified labor, the sector's image is persistently negative, which reflects a major part of the problem, as training numbers in the sector are declining [8].

4.8. What Do This Insights Mean for Innovation Processes in the Sector?

Formerly, it was likely that production was the driving force for innovations in the sector (Interview 1) see also [45]. Today, a more sustainable and efficient handling of resources is deemed necessary. These conditions suggest that it is necessary to understand the conditions under which IPs take place and identify barriers. This study gives examples of influencing factors for innovation activity and innovative capacity that are located on distinctive system levels (e.g., national policies vs. single actors' behaviors), and shows why IPs have to be organized across levels. This poses a challenge to horticultural IPs that have to deal with many uncertainties, specifics and high fragmentation. Thus, interviewees were asked about their understanding of the 'typical' horticultural IP added specifics related to IPs in horticulture. Of course, there is no such thing as a 'standard' or 'typical' IP. Rather, the idea was to identify mechanisms that occur regularly and might create sector specific barriers. With regard to this, most actors said they believe that research institutions are still initiators for innovation activity and the main producers of knowledge for innovation. This opinion seems largely motivated by the notion that research institutions have a certain research interest that could ultimately lead to an innovation, and they have the financial and human resources necessary to conduct such research, whereas SME-sized horticultural businesses normally have very little resources available. This general understanding was confirmed in the expert interviews, SWOT workshop, as well as being verified for the horticultural sector in the Delphi study. Furthermore, it is expected for science to take the lead in coordinating such processes. This is problematic since the existing research system has neither incentive for such activities nor sufficient resources or mandate. Therefore, the legitimacy of such institutions taking over this task can be questioned. As a further actor, suppliers cannot realize economies of scale and might therefore not see advantages in participating in R&D activities as the market potential for specifically modified or adapted solutions is very low.

Furthermore, due to insufficient data on the overall situation (missing energy monitoring), enterprises have difficulties expressing specific demand against other participants in the IP. This is hindering innovation ability, but could be remedied by an improved knowledge base and ongoing investment and funding of energy advisory services or energy audits [6]. A resulting problem seems to be that activities of research institutions rarely lead to innovative products for the growers' side. It seems to be difficult to find cooperation partners for projects (Interview 3, scientist, IP on breeding), mainly due to a lack of incentives on the demand side. An instrument pushing transfer is missing from the chain to promote such ideas or projects. Process coordination or process monitoring is often not at hand. This problem could be partly minimized ahead of time if growers and producers were able to communicate their requirements more clearly. Horticultural IPs are characterized by diverse interaction patterns, although according to experts the quality of cooperation exhibits a range from "diffuse" to "uncoordinated" exhibiting coordination barriers in the IP. There are a large number of small networks around specific innovations (breeding, greenhouse architecture …) in the field, although there is too little focus on communication with other sectors, which is a limiting factor. Creating a coordinated IP in which all actors have the necessary knowledge for the next step in the IP poses an enormous challenge, given the increasing complexity of such processes compared to resources available. When asked about the main obstacles in horticultural innovations, the answers ranged from economic barriers, policy barriers, knowledge transfer and communication to economic usability as well as a reluctance to implement innovations and operating according to conservative standards (see Figure 3).

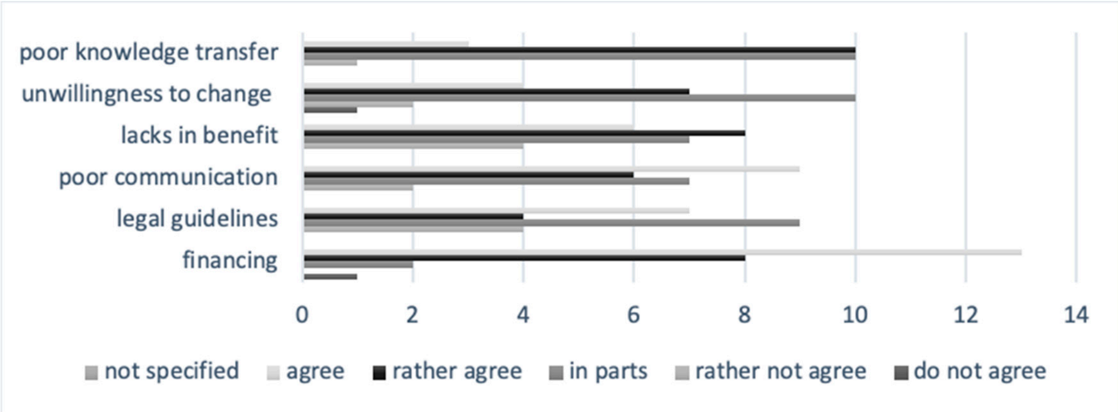

Figure 3. Most important obstacles in IPs (Delphi 2, n = 24 total number of mentions, own figure, based on [33].

Furthermore, some respondents indicated that the acceptance of innovation among consumers as well as growers is problematic. Supportive policy programs and guidelines are important for the orientation of research activities [75] and orientation of producers should therefore also seek to bring the various interdisciplinary actors together to enhance innovation activity in the sector. When asked about the success factors, economic benefit (22 mentions) was followed by high demand (16 mentions) and good cooperation (10 mentions).

5. Discussion and Conclusions

We have presented results from an explorative system study of the German horticultural innovation system, applying an SSI framework as an analytical tool across three conceptual levels and seven components [40,41]. The study explores system-related barriers for development and implementation of eco-innovations (such as energy efficient technology) into the sector and derives conclusions on how these barriers can be addressed. System frameworks are powerful tools in describing system arrangements; yet, they exhibit limitations in terms of explaining the processual, dynamic character of innovation [41,50,51]. This shortcoming was addressed by adding 'innovation processes' as a component to the analytical framework to illuminate the often-overlooked process dimension that is described as "black-box" of IPs [76]. However, SSI often leave the increasingly important dimensions of the consumers and societies role largely untouched [49] in their description of innovation activities, their triggers and barriers.

Analysis was conducted using an explorative, mixed-methods case study-based approach that was needed to facilitate a deeper understanding of the system by exploiting experts' knowledge located at different system levels and value chain steps allowing for a more thorough understanding of the complex decision-making processes within this system. A limitation of qualitative case study-based approaches is the generalizability and comparability of findings that results from a limited number of cases conducted at a specific moment in time, leading to very specific results. This study has made an effort to order in time the different methods in a way that allows validating the specific results during the research process as described in the methods section to address this challenge. Additionally, the integration of, and alternation between, different system levels enabled discourse among experts from different system levels at distinctive stages of the process, and thus, allowed for validation of results during the research.

5.1. Discussion of Barriers

We have earlier introduced EM [10] as an overarching concept that summarizes different types of eco-innovation such as processes, techniques, practices, efficiency strategies or products (ibid.). The concept of barriers is applied to explain why the implementation of eco-innovation and energy-efficiency is low, processes are delayed, or innovations are rejected [29,30] and how this can be addressed, e.g., by policy [10,45]. From results of the system analysis, we can conflate four major barrier types: *economic*, such as insufficient information, *behavioral*, such as unwillingness to change, *political/structural*, such as a lack coherent and consistent funding of IPs e.g., [15,31], and *coordination/organization*, such as lacking management competencies to coordinate complex IPs [12]. However, contemporary developments show that parts of the system have significantly changed and improved recently. These positive developments, e.g., the national energy efficiency program for agriculture and horticulture, already enable a stronger and more strategic integration of sustainability aspects than was possible before [7,13,77].

5.2. Political and Structural Barriers

We have shown how political and structural barriers [31] affect all system levels. Regarding policy and legislation, the study revealed that inconsistency (many novellas or changes in programming) increase uncertainty and encourage path dependency as a consequence, delaying IPs and discouraging innovation activity. Here, there is a need to optimize institutional environments [52] by aligning innovation objectives at the lower level with general social and environmental challenges by providing adequate and consistent programs to bring about more lasting change [50].

Results showed that the requirements for an EM have not yet been consistently translated into legislation. Some, such as the common agricultural policy of the EU, were assessed to be rather inhibiting for innovation activities, whereas the sector program for the promotion of innovation was assessed as quite relevant. However, funding programs that do not appropriately consider sector specifics increase uncertainty and delay decisions about investment or change in practices at the producer side. Newer programs, such as the energy efficiency program directed at agriculture and horticulture, offer more stability in this regard. The program is prolonged (2016–2018 and 2019–2021, with a budget of 75 million Euros for the second funding phase) and provides support for extension or for implementation of energy-efficient technologies (construction/individual measures) [7]. In this respect, the program is also able to address other barrier types such as economic. By providing funding for knowledge transfer and network building, it aims to strengthen agencies on the producer side. On the other hand, other programs that were previously assessed as positive (such as the renewable energy act, which is not directed at the sector specifically) have become less attractive for enterprises that want to use alternative fuels. Moreover, sector heterogeneity and fragmentation continue to be an important structural barrier for businesses that want to engage in innovation: despite the structural change, still more than 90% of enterprises are SMEs [3], which often need adapted solutions for their businesses. In particular, the lack of funding and support observed in the later stages of the IP during serial production or implementation in horticultural businesses will continue to be a barrier for enterprises.

5.3. Economic Barriers

Imperfect information can be found regarding growers and extension and leads to uncertainty and an attitude of mutual waiting in the sector. With respect to the latter, the situation of energy consulting and extension is starting to change, as certified energy advisers are now funded through the energy efficiency program. However, to date, this funding is more frequently used by actors from agriculture rather than horticulture [8]. Furthermore, not all consulting is followed by action [13]. Recent studies confirm that horticultural extension generally still lacks an overview of possible technical solutions and how they could be adjusted to horticulture [37]. Additionally, growers face difficulties expressing specific needs, as comprehensive situational analysis in enterprises is often not available. Consequently, suppliers cannot easily offer solutions. The necessary cross-sector communication and coordination in IPs remains limited, although the possibility of using offers for energy round tables in the frame of the energy efficiency program has emerged.

Sector heterogeneity is discussed as a straightforward economic barrier for any technology that needs an average user [29] (p. 12), which is not the case in the fragmented horticultural sector where adapted solutions are required. We have shown that economies of scale can hardly be realized on the producer side, resulting in small market potential for the many very specific products, along with a necessary adaptation of solutions to enterprise needs. Combined with low prices for horticultural products on the consumer side, this has a negative impact on profitability.

5.4. Coordination/Organizational Barriers

Innovations for horticulture are often developed outside the sector, and thus, would need also actors from adjacent fields to engage in this co-innovation processes, e.g., [38]. These processes require high coordination, iteration and negotiation competencies. However, actors that effectively take over coordination responsibility, initiate interaction in IPs between the actors and sectors involved [77] and effectively coordinate feedback loops are still missing. The question of whether actors in the chain are able to accomplish this task independently or whether an additionally intermediate structure will be necessary remains valid. The results have shown that it is rather unlikely that the very heterogenous extension system will have the necessary resources to perform this task in the future. The sector has many relevant networks, although they need to be professionalized and open to integrate up- or downstream sectors more systematically.

5.5. Behavioral Barriers

Regarding the division of roles, the sector still seems to be traditional in a way, in the sense that growers do not consider themselves as innovators. This self-perception is partially not compatible with expectations emerging from other actors in the system. Growers are still rather reluctant and seldom proactively involved in IPs, as shown before. In fact, they rather restrict their position in the system to users of innovations which has implications for the way in which they approach their role within IPs. Lack of awareness of roles increases feedback loops, delays IPs and reduces transparency of interaction patterns.

In conclusion, due to the identified barriers, eco-innovations implemented in the sector are often not systematically linked, or strategically embedded and do, thus, not consolidate in a sector strategy thus far. We conclude that system conditions as described exhibit a situation in which enterprises mostly show a reaction to anticipatory, yet sometimes already innovation-based, behavior [14]. We have described that system knowledge is partly missing, resulting in uncertainty and situations of waiting. Offers from extension and networks would help to facilitate this kind of knowledge and further support the co-innovation that is needed in the sector. Sector networks should also be more open to adjacent sectors that can provide know-how, especially for development of technology, which seems to be specifically relevant in the German context. Funding of full IPs would be a means to increase agency of growers in IPs and incentivize collaboration. Overall, changing conditions in the sector support the alignment of goals across levels or assist the development of innovation capacity [50] to increasingly consolidate sustainability issues in an overarching sector-strategy, addressing national climate and sustainability objectives.

Supplementary Materials: The following are available online at http://www.mdpi.com/2311-7524/6/2/33/s1, Table S1. List of Categories and Sub-Categories including short descriptions.

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