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Bioeconomy innovation within traditional value chains: The example of the sugar industry in three European regions

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ABSTRACT

Innovation is seen as the critical driver of a sustainable bioeconomy, but its success depends on sector specific factors and value chain configurations. The agri-food sector is characterised as being low-tech with a high centralisation of power within the value chain, which might be a barrier to innovation and the implementation of sustainable bioeconomy principles. Based on empirical findings from the sugar industry in three European regions, we argue in this paper that neither a lack of innovation, nor a purely hierarchical implementation of innovations can be unanimously supported. Evidence can be found for biomass producers that are very open to innovation and who are embedded in quite diversified regional knowledge production and diffusion systems. Nevertheless, sustainability concerns do not tend to be the main drivers of innovation in the sugar industry and innovation remains incremental. It is seen as more critical to increase efficiency, reduce costs, and add more value from side streams. As an implicit result, however, the associated innovations also promote the implementation of principles of a sustainable bioeconomy.

1. Introduction

Innovation is repeatedly named as the most dominant factor in pushing the bioeconomy towards sustainability and into a position of genuinely competing against fossil-based lock-ins (Birch, 2019; Dabbert et al., 2017; Golembiewski et al., 2015; Jander et al., 2020; Purkus et al., 2018; van Lancker et al., 2016). However, innovation dynamics in sectors that traditionally process biomass, such as the agri-food sector, are often overlooked (Wydra, 2019) or not well understood. They are, nonetheless, critical for the abovementioned transition (Jia, 2021) and sustainable interventions and innovation can also boost the competitiveness of agri-food firms (Arcese et al., 2015) in times of changing market regulations and consumer preferences.

The locus of innovation in the agri-food sector has increasingly shifted from single firms to entire value chains (Kühne et al., 2010). Value chains are considered the economic backbone of the economy and its central nervous system, managing to transform markets at local and global scales from trading in goods to trading in networks (Kano, 2018). Agri-food systems are networks of a high number of often spatially dispersed stakeholders that make independent decisions with important economic, environmental, social and health effects (Toral et al., 2011). Despite large numbers of biomass producers, agri-food systems are characterised as buyer-driven value chains with a high concentration of power among a small number of firms involved in further processing of biomass or direct contact with customers, e.g. retailers, similarly to other low-tech value chains (Gereffi and Lee, 2016).

The role of specific value chain configurations for the creation, enhancement, and capture of value has been analysed frequently in the literature (e.g. Dedrick et al., 2010). However, there has been little work done on the interdependencies between value chain configurations and innovation dynamics. In the field of bioeconomy, Wydra (2019) stands out as one of the few exceptions in this regard, but focuses on industrial biotechnology and, thus, on a presumably high-tech segment of the bioeconomy. Therefore, we see a research gap with regard to understanding how innovation dynamics are shaped by value chain configurations in traditional bioeconomy sectors. The combination of a centralised value chain, the relative maturity of the industry, and the recent pressure it has been under make it a particularly relevant case for an examination of the consequences of value chain configurations for innovation dynamics.

Against this background, this paper studies the sugar industry in three European regions as it is a well-suited example of a bioeconomy

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value chain. The value chain of the sugar industry is centralised and organised around a small number of large sugar-producing companies with regional monopolies and specialised networks of biomass producers. It is also an example of a mature industry and is often characterised as low-tech. Recently, the industry had to deal with significant changes because of the liberalisation of the EU sugar market in 2017. As a result, the industry had to focus even more on efficient production to fulfil specific regulations (Rajaeifar et al., 2019) and carry out measures to adopt circularity like installing biogas and bioethanol plants (Althoff et al., 2013; Marlander et al., 2003).

Based on a thorough characterisation of the sugar value chain, this paper aims to shed light on the consequences of a centralised and localised value chain configuration for innovation dynamics with a focus on sustainability innovation. Based on the results from three regions and three different lead firms, generalisable implications for bioeconomy innovation and the transition towards a sustainable bioeconomy will be drawn.

The next section introduces the conceptual background of innovation in value chains with a particular focus on innovation dynamics in low-tech, agri-food value chains and the corresponding specific value chain configurations. An analytical framework for interdependencies between the value chain configuration and innovation dynamics in the bioeconomy is derived from this, before section three provides an overview of the data and methods. The results with respect to the specific value chain configuration of the sugar industry and its innovation dynamics are presented in chapter four. Lastly, the fifth chapter discusses the interrelations between value chain dynamics and innovation and delivers findings that can be generalised for the bioeconomy.

2. Innovation dynamics in value chains

2.1. Innovation dynamics in low-tech, agri-food sectors

Low-tech sectors of an industry are characterised by limited levels of formal research and development (R&D) activities (Hirsch-Kreinsen & Schwinge, 2014). However, one should be critical of employing this narrow approach to examine the innovativeness of a whole sector (Kirner et al., 2009) because doing so overlooks the heterogeneity of sectors and other forms of innovation not resulting from formal R&D activities. Based on this definition, the agri-food sector is regarded as a low-tech sector (Arcese et al., 2015). Nevertheless, lots of innovative activities are present in low-tech sectors in general and in the agri-food sector in particular. For example, aspects such as the introduction of new farming or feeding systems, new food additives or flavours, or improvements in food processing technologies do not always fit the established conceptual and empirical definitions of innovation (Finco et al., 2018). Innovation is nevertheless an effective tool for supporting the transition of the sector, with incremental innovation being especially dominant in traditional and mature industries (Arcese et al., 2015).

The dominant innovation mode in low-tech sectors and specifically in the agri-food sector is doing, using, interacting (DUI, Isaksen & Nilsson, 2013). Medeiros et al. (2016) argue that the challenges in the agri-food sector can be met with complex and systemic innovations, which in turn can be achieved by adopting an open innovation approach. Open innovation was initially almost exclusively adopted by high-tech firms but it gradually became a strategic approach for traditional and mature sectors and the bioeconomy as well (van Lancker et al., 2016). Open innovation describes "the use of purposive inflows and outflows of knowledge to accelerate internal innovation and expand the markets for external use of innovation" (Chesbrough, 2012, p.20).

However, specific innovation barriers are present in the agri-food sector (Isaksen & Nilsson, 2013). For example, a lack of linkages to knowledge-based infrastructures such as universities and research institutes is mentioned because some actors in the agri-food system lack absorptive capacity. Nevertheless, it is possible that small and medium-sized enterprises (SMEs) in traditional sectors can become leaders in regional innovation dynamics based on DUI innovation (Parrilli & Radicic, 2021).

The agri-food sector has recently seen the emergence of several factors creating a need for and/or driving innovation. First, high levels of competition and price pressure have resulted in many agri-food firms focusing on increasing the efficiency of their processes and the quality of their product (Kafetzopoulos & Skalkos, 2019). In addition, more and more innovations are related to societal challenges and are aimed at solving the sustainability issues of the agri-food system (Jia, 2021; Testa et al., 2022). This reflects new environmental regulations at different spatial scales and a shift in consumer consciousness (Geels, 2010). These innovations are labelled as green, eco, or circular with many overlaps among them (Schiederig et al., 2012; D'Amato et al., 2017).

Focusing specifically on innovation in the bioeconomy, Bröring et al. (2020) presented specific innovation types and challenges. They propose four types of innovation in the bioeconomy: substitute products, new processes, new products, and new behaviours. The investigation of eco-innovation in SMEs in the food sector conducted by Cuerva et al. (2014) identified the following determinants for eco-innovation: technological and organisational capabilities, the need to catch up with competitors, increasing product differentiation, and changing customer needs, along with external influences (e.g. subsidies and collaborative networks) being highlighted as additional determinants. They conclude that the need for environmental sustainability has resulted in new pressures forcing low-tech firms to become innovative and underline that low-tech firms tend more often to innovate in green processes rather than products, however specific case studies are needed (Cuerva et al., 2014).

In the literature on bioeconomy innovation, the concepts of cascading and circularity are frequently brought up. This is not a surprise since they are part of the European guiding principle on bioeconomy as defined by the Standing Committee of Agricultural Research (SCAR) (SCAR, 2015). In addition, a recent study explored criteria for sustainable bioeconomy innovations. A crucial finding was that fostering cascading or circular systems is one of the most frequently occurring criteria (Laibach et al., 2019).

Cascading, conceptually, means using resources sequentially for different purposes through multiple material (re-)use phases, before the material, as the last step, is either used for energy extraction or recovery. At the same time, a consecutive resource circulation achieves optimal efficiency and can result in an elongated and more sustainable lifecycle of the raw material (Campbell-Johnston et al., 2020). Three different principles of cascading are mentioned by Jarre et al. (2020): cascading in time (sequential use of biomass), cascading in value (prioritisation of the most valuable use-cases), and cascading in function (co-production, e.g. in biorefineries). The circular economy, on the other hand, aims at closing resource loops as much as possible to make a material's lifecycle as regenerative and restorative as possible (Blomsma & Brennan, 2017). Since the R framework – reduce, reuse, recycle – is often named in combination with circularity (Ghisellini et al., 2016), a distinct overlap with cascading is apparent.

Regarding innovation, cascading and circularity can have a profound impact on entire value chains. Optimising the ecological footprint of a product by applying cascading of biomass or adopting a circular economy approach can increase its value and at the same time minimize resource consumption and waste production in a systemic way (Bröring et al., 2020).

2.2. Value chain configuration in the agri-food sector

The starting point for the analysis of value chain configurations in the agri-food sector is the framework by Gereffi et al. (2005) for different governance modes of global value chains. Their approach focuses specifically on relationships among actors within the value chain and its governance modes regarding coordination and power asymmetries. The form of governance has important consequences for how learning within value chains works and knowledge transfer and ultimately innovation takes place (Pietrobelli & Rabellotti, 2011). Value chain research typically focuses on lead firms (Kano, 2018) since their actions are mainly responsible for how knowledge is transferred to and between actors along the chain (Crescenzi et al., 2014). Gereffi et al. (2005) distinguished three archetypes of global value chains: modular, relational, and captive with an increasing degree of explicit coordination and power asymmetry. While higher levels of centralisation help to streamline the aims of actors along the chain and reduce unpredictability, low centralisation is believed to increase flexibility, communication, and knowledge generation, thus driving innovation processes (Giannoccaro, 2018). Therefore, an efficient and well-structured innovation system, interacting in a non-linear and endogenous fashion with a value chain, is believed to reduce transaction complexity and increase the capability to deal with complex knowledge, thus supporting the overall value chain performance (Pietrobelli & Rabellotti, 2011). According to Gereffi et al. (2005), the capabilities in the supply-base are expected to be lower for value chains with a higher power asymmetry. Combining the perspectives of innovation systems and value chains is thus considered beneficial.

Agri-food systems are considered to be “highly decentralized networks of stakeholders independently making decisions that have important economic, environmental, health and social repercussions for others [, which have] deep interdependence among [them]” (Toral et al., 2011, p. 974). However, particularly because of this high number of decentralised actors in the upstream (biomass production) segment, power is often concentrated among a limited number of firms that are processing the biomass or are close to the market (e.g. retailers). Regarding the configuration or governance, a definite answer strongly depends on the crop being cultivated, as will be discussed for the sugar industry below.

To understand the whole picture of innovation dynamics and systemic sustainability effects, value chain configurations must be considered. This represents not only an essential change in research on relationships among agricultural producers, processors, and consumers (Devaux et al., 2018), but is also regarded as a necessity by some authors (Lewandowski et al., 2019). Saetta and Caldarelli (2020), for example, noticed an increasing interest in the ecological, social, and economic effects of agri-food value chains. The term ‘sustainable supply chain management’ (SSCM) has emerged, describing a specific management type of value chains to maximize profits, increase stakeholders’ social well-being, and limiting negative environmental consequences (Hassini et al. 2012). Innovation is believed to be an integral and essential part of developing and implementing this kind of supply-chain sustainability (Kusi-Sarpong et al., 2019).

2.3. *Expected consequences of the value chain configuration for innovation dynamics in the bioeconomy*

Based on the discussion of specific characteristics of innovation dynamics and value chain features of low-tech sectors in general and the bioeconomy in particular, this section discusses potential interdependencies among them. Regarding value chain features, we focus on value chain governance and power asymmetries as proposed in the framework by Gereffi et al. (2005) its consequences for collaboration between the actors, distribution of innovation capabilities across the value chain and driving forces for innovation with a particular view on sustainability. The role of these three aspects will be further explored empirically in this paper by an examination of the sugar industry.

Power asymmetries along the value chain are expected to be high in the agri-food sector, as discussed above. Hierarchical value chains and a high concentration of innovation capabilities among few actors within the value chain could be associated with a higher risk of lock-ins and, thus, lower innovativeness. At the same time, the small size of many actors within the value chain might result in lower absorptive capacity. Power asymmetries are also expected with regard to the spatial organisation of value chains. The decision-making power might not be located within the region where the biomass is produced or processed since large, multinational firms and their subsidiaries are also involved in agri-food production. Nevertheless, hierarchical value chains could also be beneficial for an efficient diffusion of innovation if there is a productive interplay between lead firms and suppliers.

Collaboration of actors along the value chain is key for successful innovation in general, but it is of even greater importance for DUI innovations in low-tech sectors. Therefore, a high intensity and quality of interactions across the value chain and convenient locations are factors which are expected to have positive effects on innovation dynamics. The involvement of external knowledge providers might help to avoid situations in which innovation depends solely on the lead firm and reduce the risk of lock-ins. A strong collaboration among small-scale biomass producers instead of competition could also result in collective power and enable them to interact with the lead firm on an equal footing. This might increase the diffusion of innovation and lead to processes of open innovation.

Based on the literature, cost pressures and an increasing demand for sustainable production are the main *drivers of innovation* in the agri-food sector. The need for green innovation manifests itself in policy regulations and customer demands. Taking specificities of the bioeconomy into account, innovation dynamics that push the value chain towards cascading and circularity are expected to be particularly important. However, given the increasing competitive pressures in the agri-food sector, green innovations will only have a realistic chance if they also increase cost efficiency or result in additional value creation. Such synergies are expected in the use of side streams (cascading) and the introduction of circularity principles (reduce, reuse, recycle).

In the empirical analysis, we will first characterise the configuration of sugar industry value chains with respect to the governance aspects identified as relevant for innovation dynamics above. This will be followed by an assessment of regional innovation dynamics. Finally, the consequences of value chain features for innovation dynamics will be discussed along the three aspects presented in this section.

3. Data and methods

Due to a concentrated sugar market (see next section), the initial identification of the key firms was straightforward. Three out of the seven companies that presented the most optimal research conditions were chosen: Cosun Beet Company (formerly Suiker Unie; NL), Nordic Sugar A/S (since 2009 part of the German producer Nordzucker) (DK/SE) and Pfeifer & Langen (D). With the choice of these three companies, the investigation covered two cases in Germany (Mecklenburg-Western Pomerania, Saxony-Anhalt) and one in southern Sweden (Skåne). Their respective regional headquarters were in the Netherlands (Cosun Beet Company), in Denmark (Nordic Sugar/Nordzucker), and Germany (Pfeifer & Langen). This selection enabled a substantiation of the results based on the situation in three different countries and for three different lead firms. The proximity of the regions played a role as well, as they had to be sufficiently distant from each other to avoid interference, yet not too far away, so that there would be comparable social, economic and climatic settings. The rationale for multiple cases lies in the desire to uncover the flow of information and webs of relations from multiple points of view, and to thereby shed light on different configurations and governance structures to gain more in-depth insights (Buciuni & Finotto, 2016). For privacy purposes and the general aim of this work to examine how innovation, driven by which forces, occurs, certain pseudonyms will be used for actors (Table 1).

Semi-structured interviews were chosen as the method for data collection and the same five actor groups (see Fig. 1) were interviewed in each of the three regions.

In total, 15 interviews were conducted between June 2018 and July 2020 based on an interview guideline that reflects the research questions, whereby two of the interviews (V*-B and V*-C) needed to be

Table 1
Pseudonyms for interviewed actors.

	Farmer	Farmer's / Grower's Association	Sugar Factory	Knowledge Provider	Head-quarters
Case A	F-A	V-A	S-A	K-A	H-A
Case B	F-B	V-B / V* -B	S-B	K-B	H-B
Case C	F-C	V-C / V* -C	S-C	K-C	H-C

repeated. While providing consistency in the form of a standardised approach, using semi-structured interviews as a method also offers the flexibility to double down on interesting conversational paths (Lamprinopoulou et al., 2014). Interviewees were selected using purposive sampling, aiming to ensure that they had at least five years' professional experience in their field of work and a strong connection to the respective study region. The main goal was to interview one actor per region from each actor group. Another main criterion, particularly for the participating farmers, was the assumption of sustainability-oriented behaviour. Subsequent participants, especially farmers' association representatives, were furthermore often identified through snowball sampling. All participants were chosen with the aim of ensuring a good representation of each of the three case regions. To provide comparability, the categories of the interview guideline were designed to be the same for all five actor groups with small adaptations of the respective questions and regions: (1) knowledge and innovation, (2) value chain and by-products, (3) cooperation and (4) bioeconomy concepts (see App. 1 for the Farmer guideline as an example). The interviews lasted between 13 and 110 minutes and were done either face-to-face or by telephone in English or German (Table 2).

All interviews were recorded and fully transcribed in MAXQDA using the simplified transcription system by Dresing and Pehl (2018). Non-disclosure agreements were necessary in the case of some sugar factories. Direct quotes from the German interviews were translated into English.

Qualitative content analysis (QCA) provided a perfect fit as the primary method for data analysis. QCA can manage large quantities of material with the technical knowledge of the quantitative content analysis but is qualitative-interpretative in its execution, so that latent meanings can also be grasped. Therefore, the procedure is strictly rule-based, highly intersubjectively verifiable (Kuckartz, 2019) and consists of two steps. First, a criteria system must be created: either inductively, based on the material, or deductively, from the analytical framework. Although precise rules of content analysis accompany this process, it remains a qualitative-interpretive act and is referred to as deductive category application. In the second step, coding, the interview transcripts are analysed to determine whether specific categories can be assigned to multiple text passages (Gioia et al., 2013). This category-driven approach and the category system are the main instruments of the analysis (Mayring & Fenzl, 2019), with analysis units to be defined in advance. In this work, the criteria catalogue and its categories were derived deductively from the study's analytical framework and the main research questions, creating three distinct categories (1) innovation and knowledge, (2) bioeconomy characteristics and (3) value chains and their specific sub-categories. Assigning these categories to text passages of the transcribed interviews (coding) was done in MAXQDA, primarily aimed at finding answers to the formulated research questions (Kuckartz, 2019) while constantly being reanalysed and reassessed.

4. Results

4.1. Value chain configuration of the sugar industry

As a mature industry, the European sugar beet industry has a history spanning over 200 years. The EU sugar market is highly concentrated and even monopolistic at times, with only seven alliances (Südzucker, Nordzucker, Tereos, Associated British Foods, Pfeifer and Langen, Royal Cosun, Cristal Union) controlling nearly 90 % of the production, while at the same time having been protected from imports due to high duties and taxes (Maitah et al., 2016) over a 60-year period in which a quota on white sugar was in place. However, the EU market has since been liberalised and the quotas were abolished by October 2017 (Rossi, 2018): the produced quantities were no longer controlled, allowing actors in the sector to produce as much sugar as they wanted (Huyghe et al., 2020). This also meant that the EU sugar market now needed to compete globally. With third countries increasing their volumes, European sugar producers also increased their production, which led to excessive price volatility due to surpluses. The EU sugar price dropped significantly, especially compared to sugar processed from sugar cane originating

Table 2
Interview dates and durations.

Interview	Duration (in min)	Date
K-A	49:35	28/06/2018
S-A	75:59	28/06/2018
F-A	55:22	29/06/2018
H-A	96:20	06/07/2018
S-B	87:09	19/07/2018
V-A	24:05	12/09/2018
V-B	26:22	11/10/2018
F-B	42:08	06/11/2018
V* -B	27:49	10/12/2018
K-B	74:52	14/01/2019
H-B	101:57	10/07/2019
H-C	64:51	17/01/2020
S-C	53:13	17/02/2020
V-C	47:39	20/02/2020
F-C	30:50	25/02/2020
V*C	55:50	02/07/2020
K-C	13:45	09/07/2020

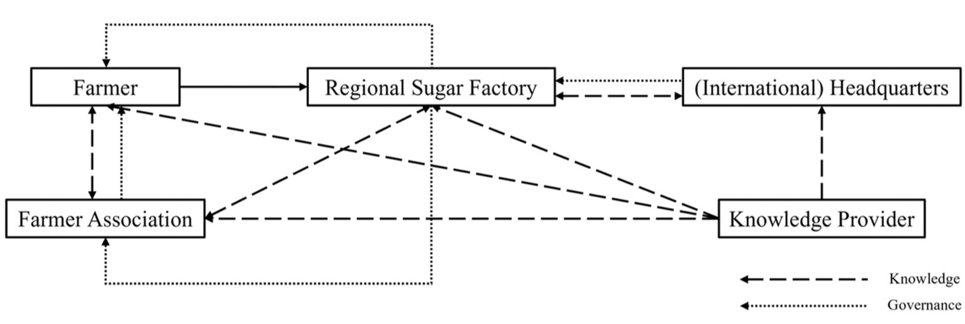

Fig. 1. Essential actor categories in the sugar beet value chain (own graphic).

from third countries, where production is much cheaper and subsidies and protective measures are often provided (Paha et al., 2021).

The supply chain of the sugar industry is, in comparison to many other industrial value chains, relatively short and typically regionally embedded. Due to short distances, sugar beets can be transported without having to deal with significant losses in quality. This simplicity also results in similar actor types being present in the value chains of different regions, with only slight variations. Usually, farmers initially procure seeds from the regional sugar factory, selecting varieties that are best suited to the specific conditions (e.g. climate, soils) of their region. The general decision-making process for the cultivation of sugar beet is thereby multifaceted, influenced by factors such as price, crop rotation requirements, soil health, and the relative ease of cultivation. During the cultivation period, fertilisation takes place, as well as pest and weed control and farmers often apply a mix of both tacit and implicit knowledge when performing these tasks (Cristóbal et al., 2016; Stevanato et al., 2019). After the annual harvesting campaign, the beets are stored near the fields, waiting to be transported to the nearest sugar factory via contractual transportation. Processing in the factory is relatively straightforward due to the maturity and ease of the process, with only minor differences existing between factories. While being very energy-intensive, processing is also characterised by a high degree of resource efficiency, with nearly all residues being utilised in some form. Nearly all by-product processes were encountered in the case regions, with steam drying, biogas, and bioethanol production being the exceptions, due to different policy and subsidy frameworks.

While not being directly involved in the outlined material chain, growers' associations possess a pivotal role in the value chain, serving as a direct proxy of the sugar beet farmers in yearly contract negotiations with the sugar factories. They also provide support to farmers in the form of knowledge-sharing as well as providing further training interventions, thus directly supporting farmers based on their needs (F-C); they organise meetings and sessions focused on helping farmers achieve better results and farming practices.

> *"The Growers' Association also works on countless other issues concerning general agricultural and environmental policy. So, we are not a political association like the Farmers' Union; we are a professional association, which means we have a very clear professional orientation. The Farmers' Union is not legitimised to negotiate prices and contracts like us" (V-C, pos.37)*

This relationship plays a decisive role in the functioning of the value chain, with trust being a key component, since farmers do give up certain freedoms: The growers' association is entrusted with key decision-making during negotiations. For this relationship to work, high levels of mutual trust among farmers and the associations are vital. Mutual interests and often shared individual backgrounds between farmers and the association representing them do of course also positively influence this connection (F-B). Since this relationship was also in place while the sugar quota was still in place, it had sufficient time to mature, while the shortness of the supply chain, and the fact that only a few actors are involved and that hierarchies between growers' associations and farmers usually tend to be flat rather than steep, had a significantly positive effect as well (F-A). Thus, the relationship is assessed favourably:

> *"[…] I personally feel well represented by it. […] And I have just seen this again recently […] that everyone is saying that the growers' association must do more so that we can achieve a better price. But when the world market is [that] competitive, the alternative is that the factory […] closes down. So […] I am happy if the growers' association manages to keep the factory alive and we farmers also compromise so that we can continue to produce sugar." (F-B, pos. 208)*

> *"Well, I think it's quite ok. […] It's quite a strong organisation […], and they know how it works and roughly where you can be in the negotiations. Because otherwise, if I had to negotiate with the industry, I think that would not be good at all." (F-A, pos.97)*

In addition, the growers' associations assess the contact with the sugar industry positively, being aware of the impact of the market liberalisation: Across all case regions, the contractual relationships are valued positively and there is also understanding in light of the recent market hardships (V-A), which left the impression of communication at eye-level. As another key actor, at least one external knowledge provider could be identified per case region, giving input for machinery development, cultivation, and providing general support knowledge-wise. How these knowledge providers are organised and financed differs and can range from research institutes specialised in sugar beet cultivation to more general agricultural research facilities. While the factories and headquarters also have connections to research and, in all cases, an R&D unit, these research organisations function as direct sources of knowledge for farmers and growers' associations alike and act as a link to the scientific world (K-A). While not occupying a central position in the supply chain, they hold a central position regarding knowledge production and diffusion, which will be discussed in more detail in the next section.

Agri-food systems were earlier described as highly decentralised. However, our findings suggest that the beet sugar industry seems to follow a rather unique path when the governance of the value chain is considered. Lead firms (headquarters) provide semi-rigid guidelines on new technologies and leave processing to their affiliated factories. Factories thus cannot decide on new technologies without approval from the headquarters: In Case A, the headquarters provides financial support for approved projects, and the factory has the freedom to manage individual approaches (H-A). In Case B, the factory operates independently, with minimal support from the headquarters (H-B). In Case C, the factory has limited freedom (H-C), with strategic planning controlled by the headquarters:

> *"[If] we look at our strategic planning in the factory, we also have small degrees of freedom there, I'll say so, it's already controlled a lot by the head office, and if not, then it is at least monitored." (S-C, pos.18)*

Some factory managers assumed regional responsibility and leadership in regional networks and asserted their position vis-à-vis the headquarters.

Considering the high level of connectedness of farmers and their respective growers' associations, the governance of the value chains framework (Gereffi et al. 2005) can be used to categorise the sugar industry value chain. First, the position of sugar factories can be seen as precarious. Despite their freedoms, from a value chain configuration point of view, they are in a hierarchically subordinate position to their headquarters and, in many cases, lack freedom of choice. While they have a certain degree of power in their processing capabilities, most critical decisions (technology, R&D projects, varieties, machinery) are only possible if made by the headquarters or in agreement with it. Therefore, in comparison to Gereffi's models, the sugar industry can be placed between the relational and the captive setting, due to the relational connection between sugar factories and growers' associations with respect to cultivation and the high dependency of local sugar factories on the respective headquarters and the relative smallness of individual farmers (see Fig. 2).

Many of these arguments can also be made for the discussion on whether the chain is centralised or decentralised. The flexibility of farmers could be an indication of low levels of centralisation, while the rather central positions and connections of, and between, growers' associations, sugar factories and headquarters tend to favour a centralised view. In the end, the most accurate description would seem to be a combination of a more decentralised lower and a more centralised upper half of the value chain.

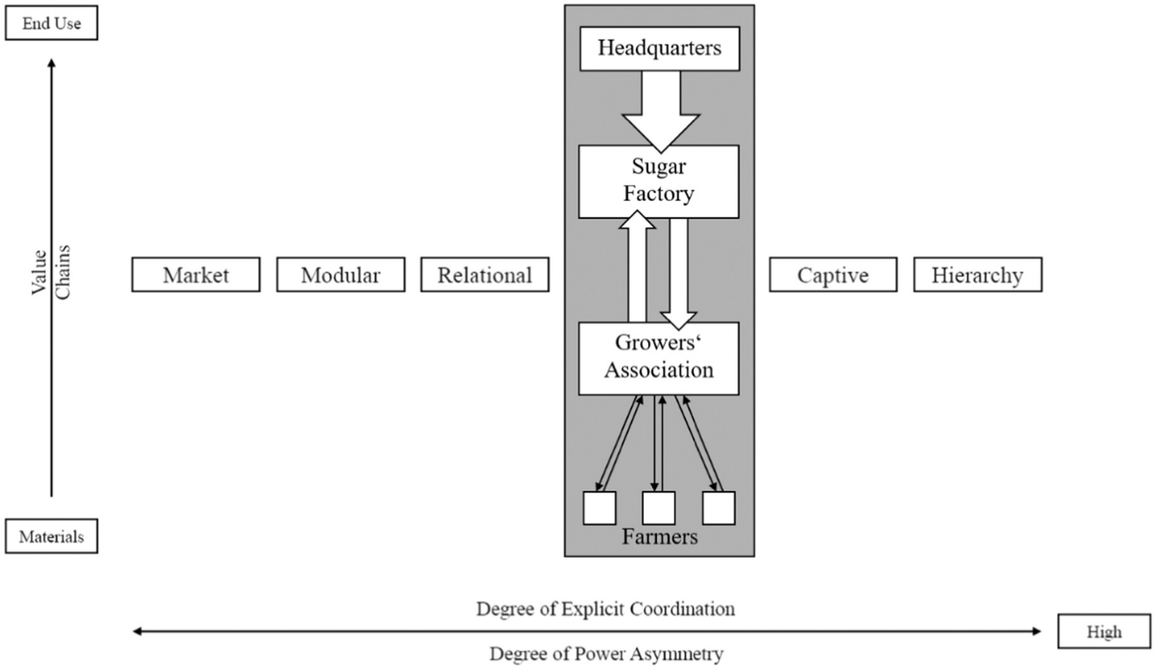

Fig. 2. Sugar value chain configuration, own graphic based on Gereffi et al. (2005).

4.2. Innovation dynamics in the sugar industry

While processing sugar has not undergone a radical technological shift for 150 years, the profession of being a farmer has changed over the past decades and now requires a broad set of skills. A recurring skill or ability seems to be a certain open-mindedness towards new things and ideas: when asked about their openness toward new methods of cultivation and subsequently their willingness to try them out, farmers responded in a similar, positive way, ranging between "happy to try something out" (F-C) to "I think it's important we do R&D; I think, it's important to research" (F-A) with other actors confirming this openness. This open-mindedness is an important factor in the ability to absorb and implement new knowledge and can function as a crucial factor for the future, as new cultivation methods and varieties in the light of climate change will require this kind of absorptive capacity.

Furthermore, observations indicate that sugar beet farmers seem to embody a dynamic of "birds of a feather flock together", with the social circle of farmers being skewed toward other farmers (F-B) and their closeness to each other but also the profession is evident. A high willingness to cooperate and interact with one another is noticeable, which is visible in the acquisition of new technology (F-A) and in general, more informal activities, like learning opportunities in the form of workshops provided by the growers' associations during the winter months (F-B). Machinery is exchanged and shared, joint accounting is discussed, and general cooperation in all matters of farming takes place (V-B), which all builds trust among farmers. Geographical proximity helps immensely with informal contacts between farmers; according to farmers' and growers' associations in all three case regions, the further away or the more extensive the farm area is, the weaker the direct connection seems. However, due to organised events and the community-orientation of farmers, even spatial distance did not seem to have a considerable impact on linkages between farmers. It is possible that farmers only interact with other farmers located on the same patch of leased land, considering others as direct competitors, which, however, was not the case in the studied regions. The connection between farmers was described as excellent, and a common identity can be underlined, bolstering trust and the possibility to minimise risk through sharing. The fields of interaction between farmers are thus both varied and numerous: ranging from ongoing casual exchanges about recent events, news, weather conditions, to cooperation during field trials with new technologies (recently in many cases, for example, drones to quickly identify patches of less-fertile land), to jointly buying and sharing expensive machines, like specialised harvesters, and in the process, forging closer ties and building trust.

The growers' associations extensively support this already valuable relationship, leading to a strongly connected and uniform cultivation side (V-A). Most of the time, the relationships between farmers are informal, and the knowledge shared is mostly know-how. Knowledge stems from close contact with primarily their respective growers' association but also from knowledge providers, for example in the form of a specialised research organisation, or in the form of advisors from the sugar factory.

Hierarchies are often flat between these actors (K-B), allowing for a more effortless flow of implicit and explicit knowledge. The growers' associations fulfil an essential role in knowledge diffusion since they are trusted partners of the farmers when it comes to the contracting with the sugar factory, and therefore knowledge communicated between them is seldom lost or unwelcome. Growers' associations also take responsibility when it comes to bundling external sources of knowledge and conveying that knowledge to farmers and thereby performing a knowledge-brokering function. They are also often the bridge enabling information from European-level knowledge providers, like the International Confederation of European Beet Growers (CIBE), to reach farmers. Since it is hard to communicate tacit knowledge by means of academic publications, knowledge providers organise field days:

> *"If, after a certain time, it turns out that a new process or a new technology brings advantages, then, of course, we put that on the Beet Meeting, for example, or in publications, etc.; that is, not in any journals, because farmers don't read that kind of thing, but they do read the farmers' newspaper, […] or the association news […]. And we also have many field days, and these are also opportunities where we can, for example, show the practitioners the trials directly and present the results." (K-B, pos.30)*

The farmers themselves confirm that linkages to academic research are often absent and that their focus is more on innovations presented to them by associations and knowledge providers (F-C). Field days, as a hands-on type of networking, have been a recurring theme in the interviews for knowledge diffusion and learning. Farmers were willing to participate, with reasons varying between free consulting and the possibility to share tacit knowledge with others and to gain new insights:

"So, just one of these cases in an area […] [is] actually […] a much more effective way than writing a report. […] I think […] it's much more time-effective, also for us because writing up a report […] is maybe a month of work, but here it takes one day of demonstration, and you immediately do it wholeheartedly. That is really something to learn from, I think." (K-A, pos.88)

Changes implemented by one farmer are quickly noticed by neighbours and, due to close relationships, often get adopted by others as well (K-A). This rather effortless knowledge spillover can be seen as an advantage in agricultural innovation systems. The proposition of the hands-on, direct approach of field trials as a method of knowledge diffusion was observed across all cases. Another aspect is that due to the high levels of interaction and cooperation driven by the farmers, their associations and the knowledge providers, certain actors serve as 'knowledge archivists' with profound experiences in their field and great influence. This knowledge archivist role is not bound to a profession, but rather describes individuals who not only gather implicit knowledge within themselves but who are also willing to share this knowledge with other actors, farmers in particular. Across the three regions, these knowledge archivists seem to have some kind of link to cultivating sugar beets and identify with it, but they do not necessarily need to be farmers.

While networks between farmers, growers' associations, and regional knowledge providers are frequently described as imperative for innovation, there is also knowledge exchange, and the interaction with the sugar factories results in learning-by-interacting, which is seen as relevant. However, this exchange is more formal and faces barriers due to the contractual relationship (S-B). While the factories are oriented more towards growers' associations and, to a lesser degree, towards knowledge providers, advisors for cultivation purposes support the farmers to ensure an optimal yield and consistent quality. This contact is regarded more as a formality amongst farmers and not as a prime way to gain new knowledge or improve cultivation practices since the farmers prefer more independent consultation (F-B). In the end, they have a broad range of possibilities to gather information and to learn, but the information load was never described as too high (F-A). It therefore seems that at least the farmers interviewed for this study have a high absorptive capacity based on their flexibility, open-mindedness, regional identity, and self-perception that favours hands-on approaches. Strong, trust-based ties help mitigate and share risks, while new information spreads quickly among them. Where this openness and a state of mind of "wanting to improve" can primarily be seen is in on-farm research, driven not least by financial pressure. On-farm research describes the collaborative effort between farmers and researchers, with the farmers making their fields available for various trials and experiments and in turn gathering knowledge from the researchers regarding new technologies and techniques:

"That means that innovative farmers always have ideas about what they want to try out and then let others participate. That means that people meet and talk about it, but they don't deal with large-scale statistical evaluations; instead, these are all ultimately experiments that are carried out on a farm and bring about an increase in knowledge. And if one person has tried something and we have discussed it, and the next person says: 'I'll try that next year too', then that is also a kind of research activity." (V-C, pos.79)*

On-farm research can thus be seen as a prime example of learning-by-doing since farmer participation is always encouraged and farmers' experience is an asset for researchers (Behera & France, 2023). In general, the DUI mode can be underlined with respect to innovation related to the cultivation of sugar beets.

The combination of these settings hints at some open innovation practices being in place in the sugar value chain. Farmers mostly have high absorptive capacity regarding new knowledge and excel in terms of relational capability. The reasons for this are to be found in a common ideology, a common goal, low hierarchies, high levels of trust and open-mindedness towards new knowledge and learning in general. One can highlight the connection to a growers' association, which functions as a knowledge broker, a connector, but also an empathetic partner that bundles and bridges interests, with knowledge providers fulfilling their role of being a gateway, or interface, to academia. Recent academic findings are monitored, filtered, and evaluated and are then provided to farmers and growers' associations.

This interface-role is crucial because new technologies, varieties, and methods stemming from rather STI-dominated modes and academic research are pushed into the innovation system. Thus, inbound knowledge entering the innovation system is technology driven by academia and seed breeders and often with a clear focus on efficiency. It finds its way into cultivation mainly via knowledge providers. Once this stage has been reached, sharing happens due to mutual trust, a supportive culture, the (absorptive) capacity and high relational capability of actors, and not least due to the sugar beet being a relatively simple resource. While there is no particular leadership in this system, as has been described the farmers themselves gave the impression of being open-minded (van Lancker et al., 2016).

Regarding the production side, the processing of sugar has not undergone any radical technological changes for 150 years. Upscaling was among the most major changes, hinting at a rather locked-in state of production (h-A). This lack of (perceived) need for radical innovation has over the years led to an increased focus on efficiency and optimisation of the underlying process. As the processing of sugar is energy-intensive, a lot of R&D-effort went into raising the processing amounts (S-A), accelerating the process, lowering energy use (H-A), and adopting circular practices by reusing by-products mainly with the goal of making the sugar factory energy independent (H-B). However, progress in optimising the process is still regarded as the main driver (S-C). Therefore, an incremental approach towards innovation can be underlined. Technology-wise, examples of process-innovation in sugar factories were mentioned: integrating a steam-dryer into the evaporation station of the factory as well as the adoption of real-time data analytics to improve the efficiency (H-A). However, most replies focused solely on the same two changes, seen as the most crucial innovations, both of which happen outside of the factories. First, the progress in seed development and breeding of new varieties has led to sugar beets that are much more resistant to insects, foliar diseases and weather conditions while growing faster and having a higher sugar content. Breeding is believed to have contributed to roughly half the yield increase over the years (K-A) and beets being more resistant to diseases and pests has helped whole regions survive (S-C). Since weight and size constitute a significant concern and are a price factor for transportation, developments in this area had to be made without also substantially increasing the size of the beets (K-C). Second, a considerable impact is attributed to progress and technology improvements in machinery and harvesting systems:

"*Breeding progress is a big part of this, as are technical innovations in agricultural technology. But […] also in the field of soil management […], harvesting technology, […] cleaning technology. […] [Therefore], yield-stabilising cultivation and soil cultivation, and then yield-securing and loss-minimising harvesting. And then the logistics chain, the beet loading system, was a decisive innovation that enabled us to build the modern logistics flows that exist today." (H-C, pos.47)*

Both, technical progress as well as progress in breeding and varieties, are based on insights in an STI setting and pushed by knowledge providers. Thus, both innovation modes find application and are intertwined due to the unique relational configuration. Farmers generate new knowledge with on-farm research (DUI), which spreads quickly due to good interlinkages, allowing for problems to reach knowledge providers in a timely manner. In addition to this bottom-up, organisational approach to innovation, a technology-push, top-down mode (STI) initiated by knowledge providers is also in place. Influenced by the general needs of the sugar industry and its market, but also by the scientific sphere in general, where research is conducted without a preceding connection to the farmers.

Thus, a certain intricate duality is evident in the innovation system, which clearly benefits from the solid relationship and trust between the actors on the cultivation side of the industry. New findings often need to be tested during field trials or in test areas, for which the farmers' communicated openness, flexibility, and absorptive capacity are especially beneficial. Innovations in cultivation also resulted in a significant push factor for the factories since they had to process much larger volumes, therefore needing improved logistics, leading in turn to more optimisation and efforts to increase efficiency (S-A).

The mindset of needing to 'make use of everything' and efficiency in processing could be observed in all the sugar companies. Since the development and implementation of new technological applications in the factories requires permission from the headquarters, they play an essential role in the innovation capacity of the factories, and in the last few years there has been an observable tendency to focus on incremental innovation:

> *"[…] We are also focusing quite immensely OK, process engineering, process optimisation, that's something where we also distinguish ourselves […], we are focusing on things which are important for us in the factories we have. It's not necessary for us to develop new types of processes, which are really unique, which we haven't tried out yet, it's really focusing on what we have at the moment and what we think is necessary for the future." (H-B, pos.56)*

A positive trait of the described hierarchical governance between the headquarters and factories is the ease of holistic development of technologies by the lead firm and then the implementation of these technologies in multiple factories (H-B). While this form of spreading knowledge and technology is targeted and done on purpose, it still leads to a faster diffusion of new technology not just in a single firm, but also across the sector, which can positively influence the development of further technologies.

While lead firms (headquarters) have their own R&D departments and also work on funded projects with universities and research organisations (h-C), it is not entirely clear whether the primary innovation mode adopted by them is STI or DUI. Judging from the observed activities and the fact that R&D departments also focus on automation, industry 4.0 and new valorisation options instead of only focusing on optimisation (H-A), STI seems the most likely. However, since mainly incremental innovation has been adopted during the last few decades, it cannot be concluded that these developments were mainly a result of STI dynamics. Sugar companies have actively participated in different research projects, which seem to focus on new products and possibilities rather than process optimisation.

For these activities, interview partners at the sugar factories also referred to distinct notions of sustainability and both circularity as well as cascading, e.g. using additional side streams like beet tops or fibre from beet pulp which can be regarded as an example of innovative activity in the sugar industry (H-A). While companies participate in joint research with academia, thereby bolstering the spread of knowledge and opening up to science, connections to competitors are only found in academic projects, if at all, but not in other fields.

Regarding an open innovation approach, some opportunities, but also challenges, are presented. Sugar factories need to have a certain absorptive capacity for the adoption of new technologies. This can often be attributed to comparatively simple processing that is indeed scalable and innovations that are incremental. However, it is to be assumed that there is a lack of trust between the factories and headquarters due to the hierarchical governance situation which was communicated in some cases, and this is a significant hurdle. A chance for open innovation can however be seen in the high degree of conformity of the sector. Thus, despite hierarchies, a fast diffusion rate of new technology and knowledge can be assumed, and due to a high absorptive capacity in the factories and pressure from lead firms, also fast implementation.

5. Discussion

The empirical insights into the configuration of value chains and regional innovation activities in the sugar industry are discussed in this section against the existing theoretical background. Regarding power asymmetries, agri-food value chains are seen as being hierarchically organised with a concentration of innovation capabilities among a small number of actors. We can partly support this statement and find evidence mainly for the upper part of the investigated value chain (see Fig. 2), in which the lead firm (headquarters) bundles nearly all innovation efforts and occupies a very dominant position in contrast to the processing factories. But even there, local sugar factories are in some cases able to pursue their own agendas to some extent. Nevertheless, power asymmetries exist with sugar firms trying to pass on competitive pressure to farmers. Sugar beet farmers try to balance this asymmetry by organising themselves in growers' associations. These associations take a central role at the production interface with the sugar factory but are much less involved in innovation activities.

Regarding the distribution of innovation capabilities, our results are partly in contrast to Isaksen & Nilsson (2013), since we did not find a lack of absorptive capacity or lack of linkages to knowledge-based infrastructures in our agri-food case, but instead found biomass producers to be very open for new knowledge and trying out innovative approaches to farming, while also communicating with one another without any noticeable hierarchies, but also with the growers' associations that advocate for them against the more hierarchically-organised processing side. Thus, we did not find substantial evidence to support the argument that the absorptive capacity is worse due to the small size of many actors. Instead, we saw that even small farmers possess the capability to not only absorb new knowledge, but to also test it relatively easily and convey insights back to knowledge providers or even other farmers.

Although the processing part of the value chain with the lead firm and sugar factories is found to be strictly hierarchical and highly centralised, that may not necessarily be a problem from an innovation perspective since novelties can be distributed across all factories efficiently. For the cultivation side, the lack of hierarchy and low centralisation works positive to some extent: the low centralisation allows increased flexibility, more direct communication, and knowledge generation in general. Our results show that, through strong linkages between actors that are usually not interrupted by hierarchies, new knowledge can enter the value chain easily and diffuses quickly, possibly even hinting at open innovation, although a deeper look into the sugar industry might be needed to confirm this claim. Nevertheless, the sugar factories seem to be disconnected from sugar beet farmers to a certain degree when it comes to innovation activities. The results suggest that there are two innovation networks at work, one among headquarters with sugar factories as their subsidiaries, one among regional knowledge providers and sugar beet farmers. The exchange between sugar factories and farmers is highly codified, focuses on the actual production, and is organised via growers' associations.

Regarding the collaboration of actors, our findings underline them as a key element for successful innovation, especially among sugar beet farmers. The existence of strong relationships to both other farmers and also knowledge providers and the overarching growers' association enables easier spreading of information and impulses to initiate DUI innovation and implement STI innovation, for example by means of on-farm research. Both the intensity, but also the quality of interaction as well as the geographical proximity are important factors for these linkages and directly influence the innovative capacity. To our surprise, we found that with respect to the innovativeness of farmers, the role of knowledge providers is considerably smaller than the potential that stems from growers' associations and their strong interrelations with farmers, despite the importance of knowledge providers for linking up with academia.

It must be stated that the most dominant drivers of innovation activities, were mainly incremental improvements in production efficiency. While the literature argues that both cascading and circularity are of great importance as bioeconomy-specific innovation dynamics, sustainability seems to be a less important driver and bioeconomy principles are often unknown to the non-academic actors along the value chain. We find that actors in cultivation and processing already apply basic principles of cascading and circularity, but they do so not because they are motivated by sustainability concerns, but instead mostly for economic reasons such as increasing value added from side streams or the use of them for on-site energy production. Thus, the scope and extent of innovations are clearly limited despite intense collaboration among farmers. This situation is possibly also a result of strong competitive pressures passed on to regional farmers by the sugar factories.

It can thus be argued that economic pressures are of greater importance than concerns about sustainability, which in turn also indicates that specific price incentives or subsidies, for example for biogas and bioethanol, can have a strong impact. Our findings therefore contradict Cuerva et al. (2014), who argued that environmental sustainability is one of the main pressures for low-tech firms, even though some principles of a sustainable bioeconomy (circularity, cascading) were by-products of a highly efficient production system. The increased demand for sustainable products also played a role. Our results hint at the fact that green innovation in the agri-food sector needs to go hand in hand with cost reduction, higher efficiency, and additional value creation.

6. Conclusion

This paper aimed at shedding light on the consequences of a centralised and localised value chain configuration for innovation dynamics. Based on results pertaining to the sugar industry, which were gathered in three European regions, some generalisable implications for bioeconomy innovation and the transition towards a sustainable bioeconomy can be drawn with a particular focus on the role of localised value-creation and innovation systems.

The results have shown that the consequences of value chain governance for innovation dynamics are not as straightforward as discussed in the literature. Based on the case of the sugar industry it has been demonstrated that agri-food value chains are not necessarily controlled throughout by lead firms – in this case parent companies of regional sugar factories. We found that innovation is, on the one hand, taking place based on the R&D activities of the headquarters and their affiliated sugar factories in hierarchical settings with certain degrees of freedom in some cases. On the other hand, sugar beet farmers were not completely powerless and dispersed, but well organised in growers' associations which could negotiate with the sugar factories in all three regions almost at eye level. Linkages with specialised research institutes and other academic partners resulted in an innovation landscape in the biomass-producing part of the value chain that was more complex than expected.

Value chain constellations affected innovation dynamics in the analysed regions and the related findings might be transferable to other parts of the agri-food industry. Farmers have shown great interest in the scientific testing and adoption of innovations. Existing networks have proven to be particularly conducive to the rapid diffusion of innovations based on trusted relationships among the farmers and the involvement of growers' associations. Innovations in agri-food industries are not necessarily limited to DUI modes. The case of the sugar industry has shown that, for example in fields like plant breeding or the application of AI in farming practices, STI modes prevail and need to be translated by intermediaries to be absorbed by farmers. Nevertheless, most innovations were rather incremental and not explicitly related to sustainability.

The results indicate that sustainability goals should not be considered in isolation when promoting regional bioeconomy innovations. As an industry facing strong international competition, the sugar industry serves as a good example of how contributions to sustainable development can be achieved as a result (e.g. cascade utilisation or circular economy) even in the case of a primacy of cost reduction, efficiency increases and exploitation of side streams due to economic considerations in the objectives for innovation projects. Economic constraints and socio-ecological desiderata must therefore be well balanced so that, ideally, they create synergies regarding innovation dynamics. As a side note, it has to be mentioned that the concept of sustainable bioeconomy was not well-known among many actors despite the fact that they are daily bioeconomy practitioners.

Finally, this study invites other researchers to further this line of study by looking into different agri-food or general low-tech examples, thereby underlining the need for a better understanding of how the bioeconomy framework is applied within different value chains. Another exciting path for future examination would be to focus more on regional comparisons and on the potential regional development paths that can be provided for lagging regions with a shift of traditional agri-food industries towards a bioeconomy framework as well as an in-depth analysis of the economic and environmental performance of innovations.

CRediT authorship contribution statement

Max Mittenzwei: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Data curation, Conceptualization. **Daniel Schiller:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Funding acquisition, Conceptualization.

Declaration of Competing Interest

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

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Appendices

Interview Guideline – Farmer

<u>I Introduction</u>

(a) *How long have you worked as a farmer?*
(b) *How has your job changed over the years?*
(c) *How large is your area under cultivation?*
(d) *How long have you been growing sugar beet? What was your reason for doing so?*
(e) *What other crops do you grow?*
(f) *How has growing sugar beet changed over the years for you? What changes have you noticed?*
(g) *Are changes to the way you grow sugar beets planned?*
(h) *In comparison to other crops, is growing sugar beet the most profitable option?*

<u>II Cooperation with the Sugar Factory</u>

(a) *What does the arrangement with the sugar factory look like? (Contract Farming?)*
(b) *If CF: How satisfied are you with the model? Is it fair from your point of view? In which areas are there clear guidelines, in which areas do you have freedom? Can these guidelines be met?*
(c) *If not: where do you get your seeds from?*
(d) *How are the beets transported and by whom? Do you see any problem in the form of transportation?*
(e) *Are there better ways of harvesting/transporting sugar beet in your opinion? If so, why aren't they applied?*
(f) *Where do you get your knowledge about innovations, new farming methods etc. from?*
(g) *If there was an innovative and profitable way of growing sugar beet, would you adopt it?*

III Cooperation with other Farmers/Farmers' association

(a) *Do you have contact with other farmers? If so, to what extent?*
(b) *Are you a member of a farmers' association or union? If so, how would you rate its work?*
(c) *Do you feel well represented by the farmers' association?*
(d) *Are there specific support programmes/policies for sugar beet farmers in your region?*

IV Bioeconomy and innovativeness

(a) *How important is sustainability to you?*
(b) *What kind of by-products (residues, wastes, leftovers on the field) do you encounter?*
(c) *How do you use these? Are they economically important for you?*
(d) *Can you imagine an even more efficient usage? What potential do you see in using them?*
(e) *In your opinion: What has been the single most important innovation in the cultivation of sugar beets over the last 20 years?*
(f) *How open to new procedures would you rate yourself?*
(g) *Have you ever heard of bioeconomy? If so, what's your opinion of it?*

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