



Sustainability in Agri-Food Systems: Transformative Trajectories toward the Post-Anthropocene

Circular agri-food economies: business models and practices in the potato industry

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Abstract

Circular economies are an important pillar of sustainable production and consumption. This particularly applies to the agri-food industry, which is characterised by large amounts of organic waste and by-product streams posing a serious challenge for many food producers. Therefore, respective firms increasingly adopt circular economy business models (CEBMs) to manage these resource flows effectively. However, there is only little knowledge on the functioning of CEBMs in bio-based industries, especially from a socio-economic perspective. We address this gap by exploring enablers and motivations behind such business models as well as the institutional contexts they are embedded in. In methodological terms, we adopt a case study approach using the example of potato production in Lower Saxony (northwest Germany). The core of the paper is a qualitative in-depth analysis of four potato processors, adopting varying business models to valorise their by-product streams (e.g. peels, scraps, pulp) either ‘in-house’ or in partnerships with external partners. The findings show that the implementation of CEBMs results from a complex interplay of internal and external enablers, with economic considerations as the main impetus for the management of biological reverse cycles. Thereby, we found a shifting economic logic in the assessment of potato by-products from disposable waste to valuable resources for other sectors (e.g. livestock farming, bioenergy, biofuels). While being encouraged by targeted policies, the companies studied feel increasingly affected by emerging sustainability discourses, prompting them to (re)design and (re)frame their CEBMs in view of environmental and societal issues.

Keywords Sustainable food systems · Circular economy · Business models · Food waste · Potato industry · Qualitative research

Introduction

Current debates on limited natural resources, growing populations and climate change increasingly emphasise the need of a circular economy as one pathway towards more sustainable futures. This idea involves a shift from the linear ‘take-make-consume-dispose’ logic to a circular system based on recycling and reusing products, components and materials, while reducing waste to a minimum (EMF 2013, 2015). The economic imperative is to keep the functional value of products as long as possible in the ‘value circle’, and to gain (additional) income from valorising waste materials by turning them into resources for other industries. A circular economy is especially relevant for agri-food industries, given their huge resource and energy consumption. In Europe alone, around 90 million tonnes of food and 700 million tonnes of crops are wasted each year, and the global

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agri-food sector consumes about 30% of all energy produced worldwide (Donner and de Vries 2021, according to FAO 2015).

Several authors have recently dealt with circular food systems (Donner et al. 2020; Jurgilevich et al. 2016; Salimi 2021; Teigiserova et al. 2020; van Zanten et al. 2019; Velasco-Muñoz et al. 2021). Especially noteworthy is the paper by Donner et al. (2020), suggesting a circular business model typology for the valorisation of agri-food waste. Based on a qualitative study of 39 company cases, the authors compile six types of business models ranging from single biogas operations to comprehensive support structures. However, despite the increasing number of both conceptual and empirical contributions in this field, there is still some lack of knowledge. For example, Velenturf et al. (2019, p. 967) point to “several research gaps including circular models for companies active in primary sectors and early stages of materials (re)processing, and tools and approaches for the increasing inclusion of multi-dimensional values across environmental, social, technical and economic domains.” The latter is also referred to by Lüdeke-Freund et al. (2019), calling for in-depth investigation of the normative values motivating certain circular economy activities (e.g. mere profit or sustainability goals), while also emphasising the need to include relational aspects and farther-reaching governance issues into analyses of circular economy business models (CEBMs).

We aim to fill these gaps by adopting an actor-centric approach that focuses on the implementation and functioning of CEBM in the agri-food sector. More precisely, we seek to understand the motivations and actions behind such models, while also considering the specific contexts in which individual agri-food firms operate. The empirical analysis is guided by two research questions:

- What are the main enablers behind the establishment of CEBM in the agri-food sector? To what extent are the firms affected by environmental, social and economic issues?
- How does the institutional environment affect the design of CEBM? How do agri-food firms adapt to changing economic and political conditions in that respect?

Answering these questions, we address the importance of (multi-dimensional) values and governance mechanisms, which have been identified by Velenturf et al. (2019) and Lüdeke-Freund et al. (2019) as areas of further investigation in CEBM research. From a conceptual viewpoint, this study is informed by the Ellen Macarthur Foundation (EMF) and its well-known Circular Economy Butterfly diagram, including both technical and biological reverse cycles as a constitutive element of circular economies (EMF 2015). Recently, the EMF approach has been refined by Lüdeke-Freund et al.’s

(2019) compilation of six major CEBM patterns, with two of them—cascading and repurposing, and organic feedstock—especially relating to the agri-food sector (see also next section).

The empirical base of this paper is part of a collaborative research project dealing with organic waste and by-product valorisation in large-scale crop production. The findings discussed are derived from selected firm case studies in the potato industry of Lower Saxony, which is one of the most important agri-food regions throughout Germany. Due to its large amounts of by-products occurring along the value chain (i.e. peels, scraps, pulp, fruit water, damaged/infected potatoes), the potato industry is a relevant example demonstrating the need for a circular economy. However, respective efforts at firm level have not been explored in much detail so far. Findings will allow us to gain new conceptual and management insights into business models aiming at the valorisation of organic waste products, and may be applicable for different agri-food industries.

The paper is divided into six parts. Following the “Introduction”, Section “Conceptual Framework” outlines the Conceptual Framework referring to recent literature on sustainable business models in general and CEBMs in particular. In Section “Materials and methods”, research methods and materials are described. This is followed by the empirical results, including both a brief overview of circular economy activities in the potato sector of Lower Saxony and in-depth analyses of four processing companies to answer the main research questions. In Section “Empirical results”, the findings are discussed in relation to other empirical studies on circular agri-food economies, while Section “Conclusions” provides a short summary and some directions for future research.

Conceptual framework

This paper draws upon academic debates on circular economy business models. A business model, in general, articulates how the company in question converts resources and capabilities into economic value, with implicit assumptions about customers, competitors, revenues, costs, and distribution channels (Teece 2010). Richardson (2008) and Bocken et al. (2014) define three strategic essentials of any business model: (1) value proposition, i.e. product and service offerings, customer base, customer relationships; (2) value creation and delivery, i.e. activities, resources, technologies, partners, distribution channels; and (3) value capture, i.e. cost structures, revenue streams, new business opportunities. Moreover, Boons and Lüdeke-Freund (2013) explicitly relate business models to innovation activities and networks which they regard as a “mediator for innovations that not only links production and consumption but also embraces stakeholders

and their expectations from non-business areas” (Boons and Lüdeke-Freund 2013, p. 16). A business model—whether chosen knowingly or unknowingly—may be critical for enabling innovation and supporting customer value creation (Teece 2010).

In contrast to ‘classic’ business models usually aiming at maximising economic value, a sustainability-oriented business model focuses on creating benefits for a broader range of stakeholders while also considering environmental and social values (Schaltegger et al 2016). There is a broad variety of strategies and measures that may be integral to sustainable business models (SBMs), e.g. using renewable resources, developing sustainable technological innovations, engaging with responsible suppliers, driving more sustainable consumption, or ensuring fair redistribution of income and expenditure between parties (Boons and Lüdeke-Freund 2013; D’Amato et al. 2020). Fostering the development of SBMs in theory and practice, Bocken et al. (2014) suggest eight SBM archetypes: maximise material and energy efficiency; create value from waste; substitute with renewables and natural processes; deliver functionality rather than ownership; adopt a stewardship role; encourage sufficiency; repurpose the business for society/environment; and develop scale-up solutions. This categorisation not only provides options for reducing negative environmental and social externalities, but also assists in creating business models that achieve higher levels of sustainability. This will require businesses to address a number of “emerging themes (...), including: the role of technology advancement and level of innovation, the application of a systems perspective, introducing innovative approaches to collaboration, and the need for education and raising awareness to facilitate successful adoption of sustainable business models” (Bocken et al. 2014, p. 54).

One possible way to accelerate the transformation to a more sustainable economy relates to the implementation of circular economy principles at the firm level. Geissdoerfer et al. (2017, p. 759) define the circular economy (CE) as “a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops.” According to the EMF (2015), a CE rests on three principles: preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows; optimise resource yields by circulating products, components, and materials at the highest utility at all times in both technical and biological cycles; foster system effectiveness by revealing and eliminating negative externalities for environment and society. Applying these principles means creating an economy that provides multiple value-creation mechanisms decoupled from the consumption of finite resources or, in other words, an economy that is restorative and regenerative (Fig. 1). However, Hobson and

Lynch (2016) go a step further by questioning the technology-drivenness of many CE concepts due to inherent risks of overlooking the actual roots of the ‘resource crunch’, i.e. over and wasteful production and consumption. In this light, Schulz et al. (2019) plead for a broad understanding of CE that looks beyond the market economy and the technicalities of CE implementation, while also considering the kind of products, production organisation, and resulting consumption patterns and socio-ecological externalities.

The way of in which CE is practiced at the firm level depends on the chosen circular economy business model (CEBM). A CEBM can be defined as “the rationale of how an organisation creates, delivers, and captures value with and within closed material loops” (Mentink 2014, p. 35). Thus, the overarching goal of a CEBM is to generate value through using resources in multiple cycles and, simultaneously, reducing waste materials that otherwise must be disposed of. In this regard, Lüdeke-Freund et al. (2019, p. 41) point to the formation of new markets for secondary resources, while the resulting resource flows may lead to cross-sectoral relations “that allow for multiple resource use, cascading and biorefining, continuous recycling, or even the emergence of IS [industrial symbiosis] networks based on spatial proximity.” The authors further provide a typology of six major CEBM patterns that are mainly derived from the EMF’s ‘butterfly diagram’: repair and maintenance; reuse and redistribution; refurbishment and remanufacturing; recycling; cascading and repurposing; organic feedstock (Lüdeke-Freund et al. 2019, pp. 45–53).

With regard to the agri-food sector, CEBMs are primarily focused on the valorisation of organic materials, such as waste, residues or by-products, in a cyclical or cascading manner. This ambition is clearly reflected by the biological reverse cycles of the two latter CEBM patterns, i.e. cascading and repurposing, and organic feedstock. The principle of cascading biomass use originates from the forestry sector and has been proposed to achieve both a higher degree of resource efficiency and a significant reduction of greenhouse gas emissions (Keegan et al. 2013). In practice, cascading models describe the iterative use of biomass for higher-added-value products, as material input for further processing or as a source of energy recovery. Therefore, value creation is based on exploiting the biological nutrients contained in products, used materials, and waste. Once all feasible cascades are used, organic feedstock conversion is an alternative, though partly overlapping, option for closing material loops in agri-food production. The major value proposition relies on the use of green and organic-based inputs that can be processed via extraction or anaerobic digestion (Lüdeke-Freund et al. 2019). Organic feedstocks are usually converted into liquid biofuels and biogas, however with limited potential of

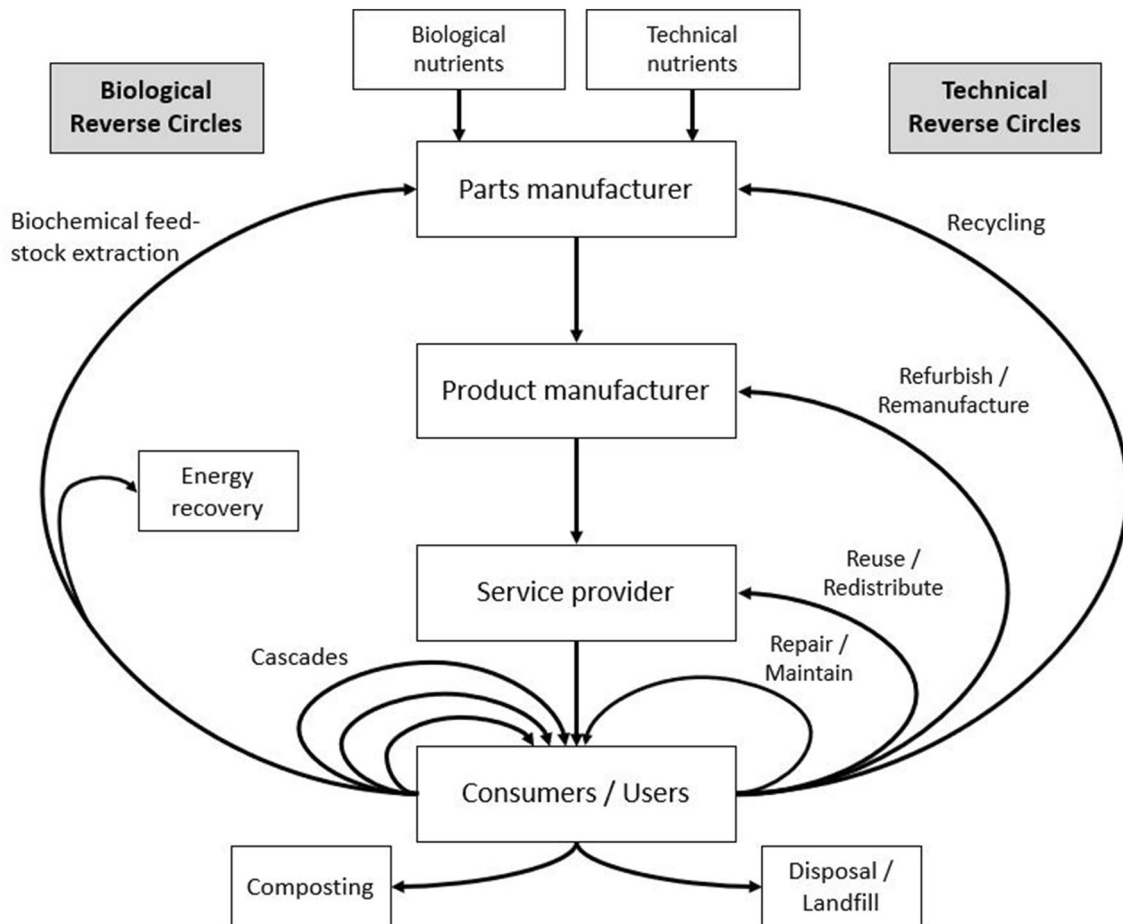


Fig. 1 Reverse cycles in a circular economy ('butterfly diagram'; adapted from EMF 2015)

value creation. In sum, cascading and organic feedstock models aim at retaining the value of biological materials, while being inspired by the ecological rationale of 'waste is food' (as an element of the 'cradle-to-cradle' concept; see Braungart et al. 2007).

Following from these conceptual thoughts, we seek to analyse the functioning and context of CEBM using the example of the potato industry, which is characterised by large amounts of organic waste and by-products occurring along the value chain, i.e. damaged/infected potatoes, peels, scraps, misshapes, pulp, fruit water. Based on in-depth firm case studies, the analyses will allow a better understanding of practical applications of CE principles through specific business model designs, thereby providing empirical evidence with regard to the biological reverse cycles as suggested in the concepts by EMF (2015) and Lüdeke-Freund et al. (2019). In doing so, we also respond to a recent appeal by Donner et al. (2020) who argue that the valorisation of agricultural waste materials have often been considered from a technological perspective, but much less from a socio-economic one—neither yet in the

context of sustainable or circular business models nor in a typology of models.

Materials and methods

The empirical analyses are part of a working package within a larger interdisciplinary research project entitled 'Bioeconomy 2.0: Innovative potentials of agri-food by-products'. The geographical focus is on Lower Saxony in northwest Germany, where intensive agriculture and food production are predominant elements of regional economies and cultural landscapes. Three plant-based production systems have been addressed in the project, i.e. potato, rapeseed and sugar beet production. However, this paper rests on a sub-project dealing with by-product valorisation in the potato sector. In Lower Saxony, potato production clearly stands out since almost one in every two German potatoes is grown there, meaning a total harvest volume of around 4.1 million tonnes produced on an area of 114,000 hectares (BLE 2019; Fig. 2). In addition, there are 17 potato processing

Fig. 2 Main areas of potato production in Lower Saxony (according to harvest volumes at district level in 2016) (More recent data at district level are not available; highlighted are only those districts with a minimum harvest volume of 200,000 tons). Source: Own figure; data adapted from Destatis (2016)



companies located in Lower Saxony making up at least 20% of all German potato processors (Destatis 2019; LSN 2019). Some of them are among the largest potato processors in Germany in terms of annual turnover and number of employees. The strong concentration of potato production in Lower Saxony can be explained by the widespread sandy soils, which provide very good natural conditions for potato production at a large scale.

The research is based on 28 guided expert interviews with representatives of the potato industry. These include twelve potato farmers, nine processing companies, two intermediary traders, one retailer, one input supplier, two industry associations and one research institute. The selection of interview partners intends to reflect the heterogeneity of actors along the ‘potato chain’ in terms of company size, distribution channels, amounts of waste, and other features. For this purpose, we initially collected a set of company data to prepare the interview sample. A particular focus was laid on the selection of potato processors, as the largest quantities

of waste and by-products usually occur at the processing stage. Therefore, processing companies are expected to provide differentiated insights into the implementation, functioning and context of CEBMs. The 28 interviews delivered valuable insights on the organisation of value chains, the interaction between farmers, processors and retailers, and the occurrence and (possible) utilisation of waste and by-products. These findings were useful to get an overview of general structures and spatialities of the potato industry and the evolution of circular resource flows.

To consolidate the findings drawn from the interview sample, we took a closer look at four (of the nine) potato processors chosen by means of purposive sampling. The selection was driven by self-descriptions of the companies as in some way implementing circular flows of waste and by-product valorisation. The four case studies are the ‘empirical core’ of the paper, as they allow for in-depth analyses of CEBMs in terms of motivation and goals, organisation and (cross-sectoral) interaction, enablers and constraints,

and external factors. Two of the four potato processors also offered on-site visits to show the production processes with a special focus on circular flows and the utilisation of by-products. The information provided during these visits expanded the results of the interviews and content analyses from a practical viewpoint. Finally, a number of firm-specific documents such as [company profiles](#), key figures and data, business model descriptions, sustainability reports, graphical abstracts, newsletters, and other contents have been collected and analysed. These materials were either available on the firms' websites or handed over directly during the interviews.

The interview partners were mostly contacted via e-mail. If no e-mail address was available, we contacted them via telephone (this only applies to potato farmers). Some interviews were acquired by 'snowball sampling', with an industry association¹ functioning as a kind of 'door opener'. The interviews were carried out face-to-face between November 2017 and September 2018; their duration was 60 min on average, but varied from 40 to 160 min. The interview guideline was organised differently depending on the role and function of the interview partner in question, but in general consists of four thematic categories mainly derived from the literature: business network of the company (e.g. supplier-customer relations, position in the value chain); forms and amount of potato by-products; functioning of CEBM, i.e. practices of by-product valorisation (and the goals and motivations behind); external conditions affecting the CEBM (e.g. political environment, legislative framework). In almost all cases, the interview partners agreed to record the interviews to literally transcript the material afterwards. Transcripts were evaluated and interpreted by content analysis according to Mayring (2014) using his techniques of 'summarising' and 'inductive category formation'. 'On that basis, the collected material was organised, reduced and consolidated in the form of 'case summaries', before more sophisticated interpretations in relation to the categories developed were made.

Empirical results

The empirical findings derived from the interviews are organised in a two-step manner: first, we provide a concise summary of CE practices adopted by potato farmers and processors in Lower Saxony. This overview draws a general picture regarding the utilisation of potato by-products and related business models. Second, we deeply analyse four

potato processing firms of different size, product range, distribution channels, and location conditions for better understanding the implementation and development of CEBMs 'on the ground'. A particular focus lies on the main enablers and contextualities affecting the firms' business models, which will contribute to refine existing knowledge on the functioning of biological reverse cycles in CEBMs.

Circular flows of potato by-products—an overview

The spatial concentration of potato production in Lower Saxony results in large amounts of organic waste and by-products in the form of peels, scraps, misshapes, damaged or infected potatoes, pulp,² and fruit water. The much larger proportion of this biomass is produced at the processing stage, where all types of by-products occur. But potato farmers may also generate significant volumes of by-products, i.e. misshaped, infected or damaged potatoes. According to the interviewees, the accumulation of these organic materials varies between 15 and 50% of the total production volume, depending on company type (farmers or processors), processing methods, peeling processes, storage capacities, and physio-geographical conditions (weather, soil). Given this, the utilisation of by-products has become an important issue among potato farmers and processors in Lower Saxony, especially in terms of value creation and sustainability aspects (Jorissen et al. 2018; Nier et al. 2018). The valorisation pathways identified reveal the establishment of more or less targeted business models, connecting different, though related, bio-based industries in multi-use systems.

The most frequently used option for the valorisation of potato by-products is livestock feeding, particularly in dairy and cattle farming. Basically, all types of by-products can be transformed into livestock feed. Regarding the pig sector, however, the by-products must be cooked prior to feeding, otherwise the pigs will not be able to digest potatoes and potato by-products. What makes it quite comfortable for potato farmers and processors is the fact that livestock farmers usually take charge for collection and transportation. Another option relates to renewable energy production, with again all types of potato by-products being suitable substrates for biogas plants. Due to the limited profitability of these pathways, the resource flows usually take place within a small radius of no more than 20 km. Otherwise, the costs for transportation would outweigh the added-value through energetic utilisation. At least five potato processors (of the nine interviewed processors) run their own biogas facilities fed by organic waste biomass. Further alternatives

¹ The association is the 'Bundesverband der obst-, gemüse- und kartoffelverarbeitenden Industrie e.V. (BOGK)'; an appropriate english translation is not available.

² Potato pulp is a waste product arising from the extraction of potato starch. It consists of potato peel, remnants of the cell walls, traces of starch, and 85–90% water with dissolved mineral salts (Mayer 2016).

for the valorisation of potato by-products in circular systems are starch production, fertilisation and pet food production. However, only a few companies make use of these opportunities, as they require certain processes, technologies, and logistics. This aspect and related CEBMs are presented in more detail in the next section.

Basically, the location of potato farmers and processors in Lower Saxony as one of Germany's leading agricultural regions is advantageous for CEBMs that rely on partnerships with livestock farmers, biogas producers or feed companies from the local area. Such relations are typical in the Weser-Ems region in the western part of Lower Saxony, showing the highest density of livestock farming operations and biogas facilities throughout Germany. Given that the economic value of potato by-products is rather low, many interview partners mentioned that they primarily seek to avoid disposal, which will cause additional costs and bureaucratic efforts.

“Currently, the materials are completely collected – and that's really important. We only have limited storage capacities. Actually, it is a ‘zero sum game’. We are happy, if we have no costs. It also depends on the region. There are many livestock farms in this area and that's a good precondition to get the stuff off” (interview starch producer).

As this quote may indicate, potato farmers and processors try to find easy ways for the recovery of by-products, looking for potential buyers to build loose and spontaneous relations that may create ‘win–win’ situations for both parties. The collaboration with the users of by-products often rests upon acquaintance or word-of-mouth recommendations. Transportation is mostly carried out by the customers, who only have to pay small prices for the by-products or even get them for free. Therefore, contract agreements are rather the exception than the rule. This may imply that CEBMs in the potato sector are not so much driven by long-term calculations and intended outcomes, but rather by local conventions and incidental opportunities.

The viability of CEBMs is also affected by general developments in the potato market, which shows strong fluctuations in prices from year to year. In low price periods due to oversupply (for example, in climatic favourable years), there is often additional demand for surplus potatoes by livestock farmers. A similar situation can be observed in times of higher feed prices, which again leads to an increasing demand for potato by-products from the livestock farming sector. Realising a CEBM in the potato industry, thus, requires certain adaptations to changing market conditions.

“Every year, we see different demand by different customers. It depends a little on the price gap between specific market areas. (...). Currently, conventional

livestock feed is scarce and expensive, which is why the bulk of by-products are fed at the moment. It is affordable feed for the farmers, and it is suitable for dairy cows and cattle. Exploiting such opportunities is an important part of our business model” (interview potato peeler and packager).

This brief overview revealed how potato by-products circulate in multi-use systems, and how these flows are shaped by different material, spatial and institutional dimensions. We now provide four case studies for detailed exploration of CEBMs based on organic waste and by-product valorisation. All cases are potato processors varying in firm size, volume of by-products, capabilities, know-how and location. This sample will provide a more nuanced picture on the functioning of CEBMs and their organisational and contextual characteristics.

Specificities of CEBMs in the potato industry—four case studies

In this section, we first introduce the four study cases by presenting brief profiles of each company. These include information on the organisational structure (origin, employees, turnovers, location), product range, suppliers and customers. Next, the main enablers and motivations behind the development of CEBMs are analysed and summarised. Finally, the business environment and political-economic relations are scrutinised to better understand the influence of context conditions on CEBMs.

Company profiles

Company 1 is a large international potato processor, which was founded in 1962. Today, the firm runs eight production sites alone in Germany, besides other locations in Belgium, Denmark, the Netherlands, Poland, Spain and Sweden. Its head quarter and main production site are located in the western part of Lower Saxony amidst an area of most intensive agriculture and food production. The corporate group has over 4000 employees in total, with around 1150 working at the company's central location in western Lower Saxony. Based on a broad product range of processed potatoes (e.g. French fries, home fries, croquettes, wedges, gratins, potato salads), the annual turnover of the whole corporation was almost 1.4 billion euro in 2019. The customer base consists of food retailers (supermarkets, discount stores), wholesalers, caterers and industrial partners at national and international level. The company has continued to grow over the years, and is now a market-leader for fresh and frozen potato products. In the recent past, the strategic focus has increasingly shifted towards sustainability issues, leading to the

company's first sustainability report launched in 2019. The corporate sustainability strategy is largely driven by optimisation of resource use and more effective utilisation (and reduction) of potato by-products. In this regard, a CEBM has been developed in a step-by-step manner, which is permanently refined and modified.

Company 2 is another large potato processor, running two production sites in western Lower Saxony (main location of the company) and in Saxony-Anhalt near the city of Magdeburg. Founded in 1967, the company has undergone a steady development focusing on frozen potato products (e.g. French fries, croquettes, wedges, potato pancakes). With a workforce of around 800 employees, the annual turnover was almost 250 million euro in 2018. Main customers are food retailers, wholesalers and fast food chains (e.g. McDonald's). The firm is further characterised by a high degree of internationalisation and an integrated contract farming system, involving more than 200 potato farmers. These farmers are subject to strict principles and controls, and they are trained by agricultural engineers to adopt sustainable farming practices (e.g. soil and energy management, adjusted fertilisation, varied crop rotation, environment-friendly recycling, nature and landscape management). Against this background, the company describes itself as "strictly following the responsible principles of a sustainability-oriented corporate philosophy" (firm's website). A core element behind this philosophy is a CEBM based on sustainable energy and water management and a holistic strategy of by-product valorisation.

Company 3 is a small potato peeler and packager, located in the eastern part of Lower Saxony. This area offers favourable natural conditions for potato cultivation due to its sandy soils. The company was founded in 2001 by ten potato farmers from the region. Their motivation was to become less dependent on other potato processors and traders, while keeping more added-value 'in-house'. Today, the firm has around 60 employees, taking charge of peeling, packaging and distributing different sorts of fresh potatoes. Suppliers are the ten company-owning farmers as well as further potato farmers from the region. The potatoes are sold throughout northern Germany with the metropolitan region of Hamburg as the most important market area. The customer base is rather diverse, including food retailers (supermarkets, discount stores), wholesalers, restaurants, caterers, business canteens, universities, schools, hospitals, and other social facilities (e.g. nursing homes, kindergartens). Due to the huge amount of potato peels and scraps that occur during the peeling process, the company is more or less compelled to create a CEBM based on by-product valorisation. In recent years, this CEBM has become more sophisticated and is now an important pillar of the company's value creation process.

Company 4 is also a small potato processor, focusing on a special type of potato chips ('Kesselchips'). The company is located in the south-central part of Lower Saxony and employs around 40 workers. Founded in 2010 by two cousins, the firm has developed successfully within a short period of time. One reason for this may relate to the fact that the potatoes are exclusively delivered by the firm's own potato farm, thus allowing them to gain full control over the supply chain. Both transaction and transport costs are very low as the potato farm is situated only a few hundred meters from the processing plant. Due to the low quantities of potatoes processed annually (around 12,000 tonnes) and the high degree of product specialisation, the company can be described as a 'niche player' in a competitive potato market. Nevertheless, it has also achieved a certain reputation as a contract manufacturer for well-known brand producers. These branded products are sold via larger food retailers and wholesalers at national and international levels. By contrast, the firm's own specialities are distributed regionally, especially via farm shops or independent supermarkets. The by-product streams are rather different from those of the other companies, particularly as peels are almost completely used in the production process. Instead, waste oil occurs as the main by-product, which is managed purposefully to generate additional value.

Designing CEBMs—enablers, motives, practices

The brief overview of the four companies already indicates the existence of individual CEBMs, in which specific forms of potato by-products are converted into new inputs for different economic activities and processes. The four CEBMs and related resource/by-product flows are illustrated in Figs. 3, 4, 5 and 6. Therefore, company 1 runs its own biogas plant for internal use of by-products, with the energy produced being fed into both the energy cycle of the firm and the public heat grid of the municipality (Fig. 3). Surplus biomass is used for external production of bioenergy and livestock feeding, while extracted starch as another by-product stream is sold to international starch processors. The CEBM of company 2 rests on various pathways of by-product valorisation involving different actors (bioenergy producers, livestock farmers, bioethanol producers, waste oil processors), while at least the energy cycle is closed 'in-house' by means of an anaerobic water treatment plant (Fig. 4). By contrast, company 3 seeks to valorise the bulk of its by-products 'in-house' (Fig. 5). Fostered by the agricultural origin of the company (founded by ten local farmers), two biogas plants and three pig barns have been successively built up to absorb the huge amounts of peels and scraps that occur during the peeling process. The energy surplus generated from the biogas plants is fed into the local heat grid (at village level), while surplus by-products are sold to local

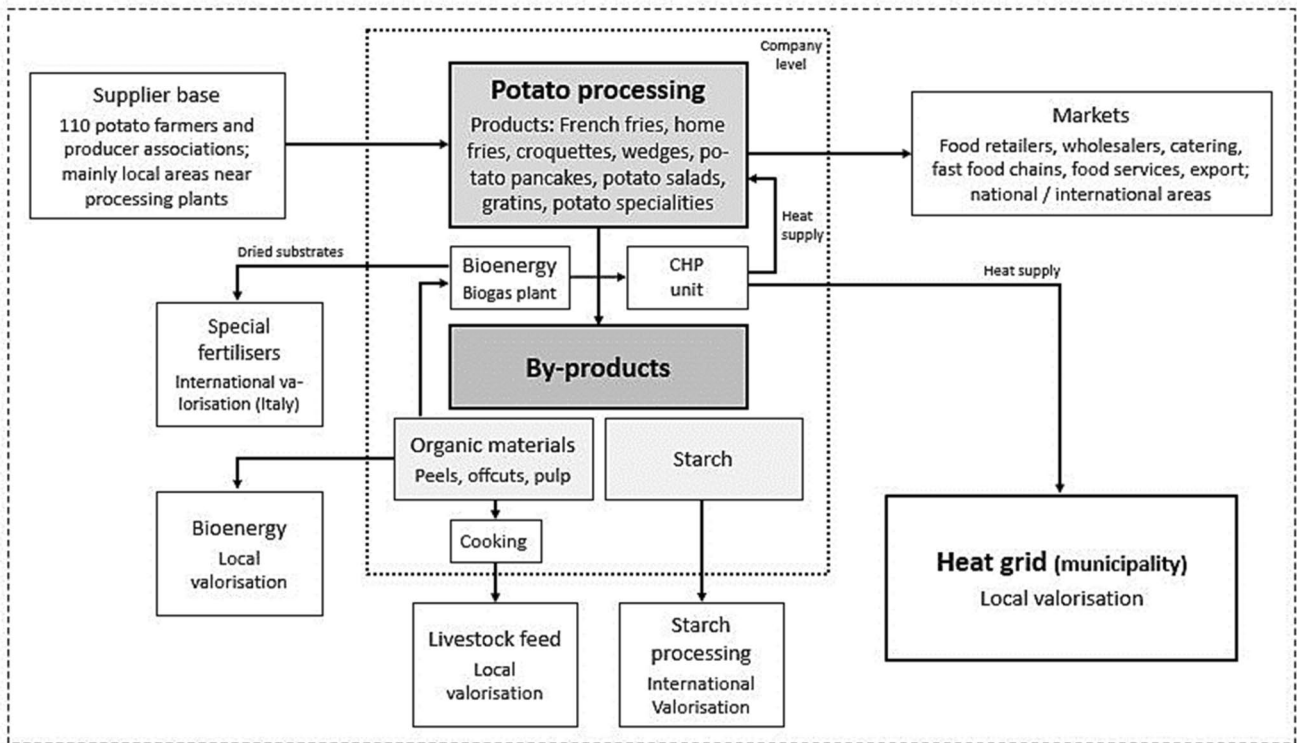


Fig. 3 CEBM of company 1

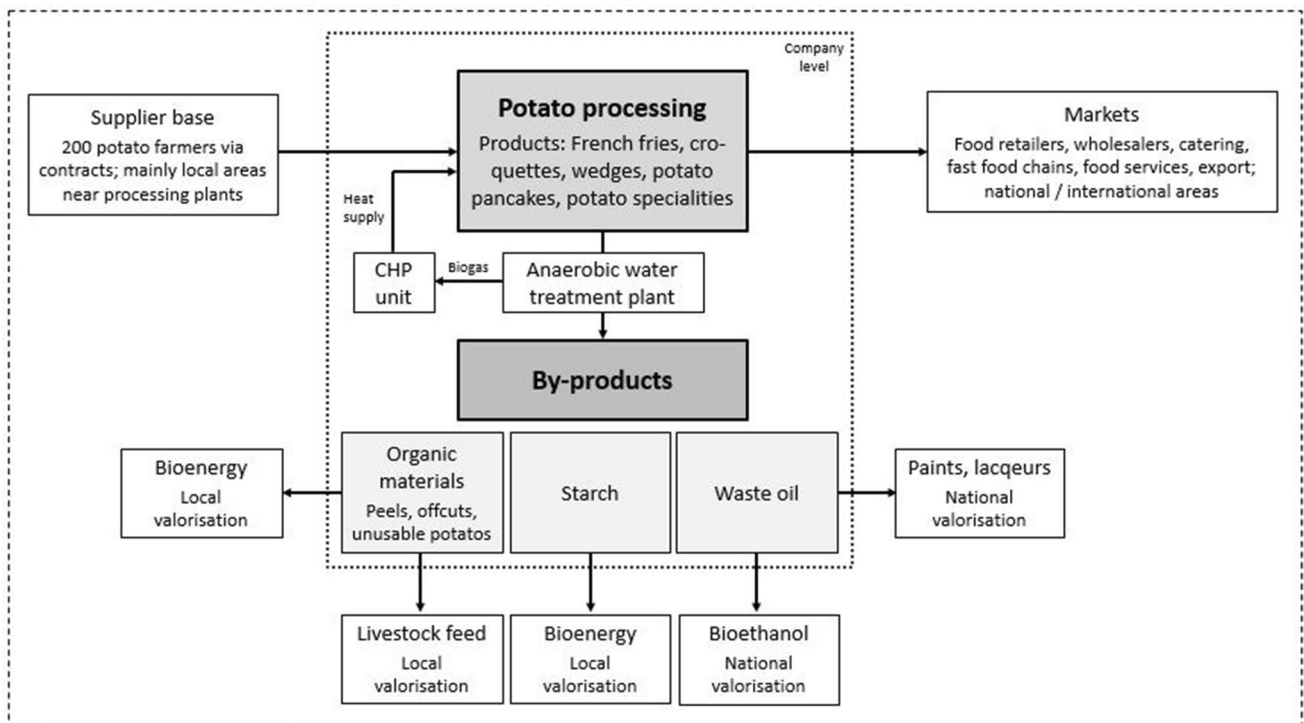


Fig. 4 CEBM of company 2

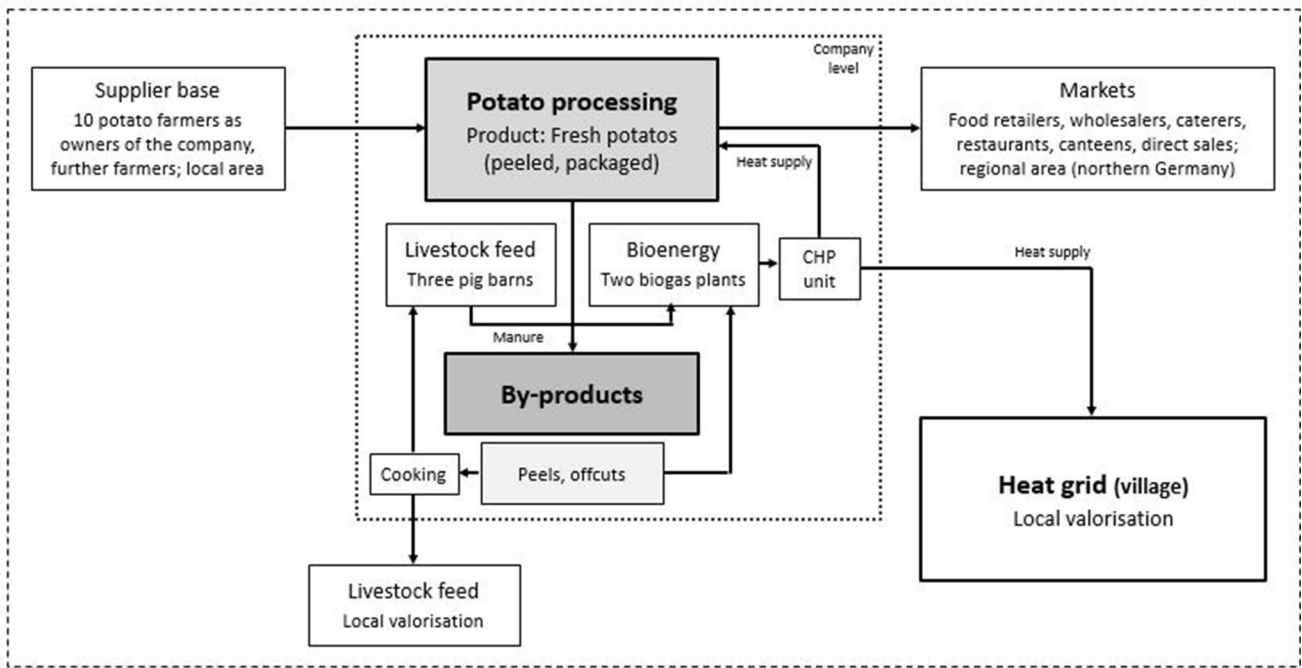


Fig. 5 CEBM of company 3

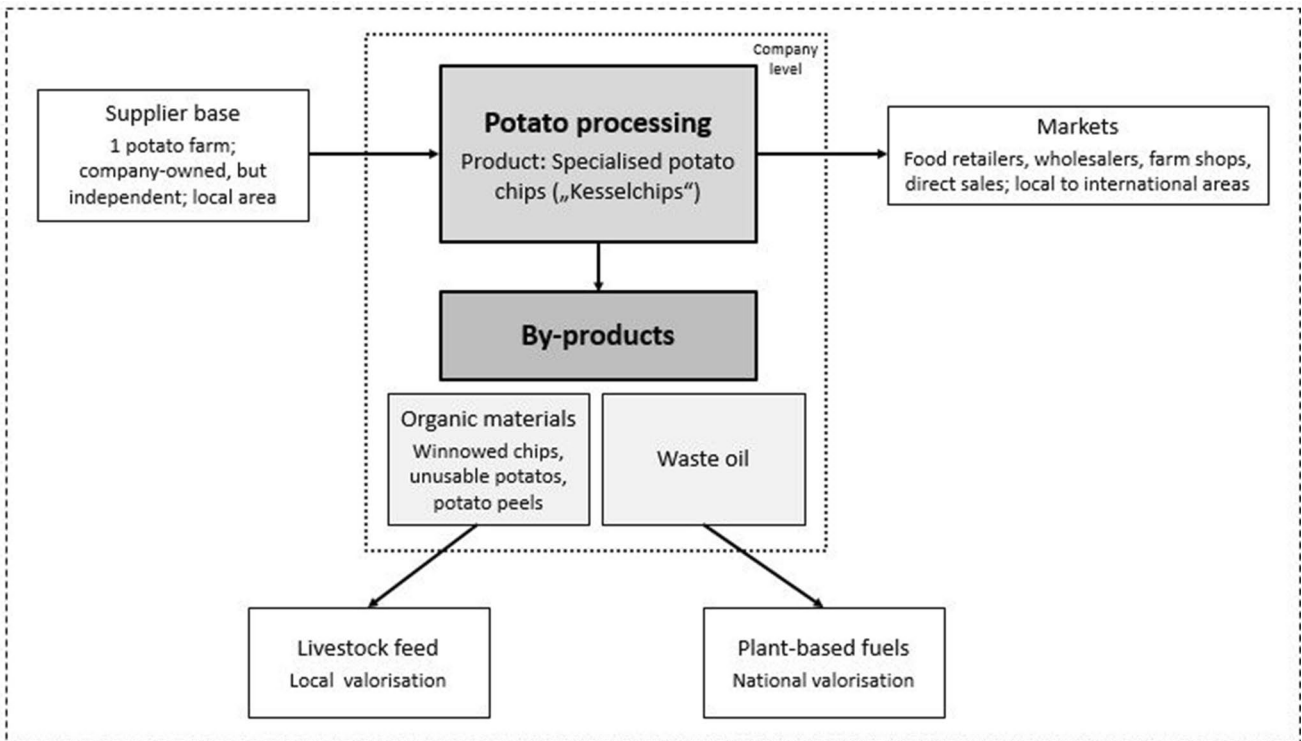


Fig. 6 CEBM of company 4

livestock farmers. Finally, company 4 adopts a rather simple, but profitable CEBM based on the valorisation of waste oil to generate plant-based fuels (Fig. 6). While the prices for waste oil have clearly increased in recent years (from 40 cent up to 70 cent per kilogram, according to the interviewee), this pathway has meanwhile become an important pillar of the firm's value creation process. By comparison, the utilisation of other by-products as livestock feed can be almost neglected alone due to their relatively low quantities.

In all four companies, the development of CEBMs results from the necessity to deal with large amounts of potato by-products, even though the companies continuously seek to minimise their by-product streams. As these possibilities are largely exhausted, the need to implement a CEBM is somewhat inevitable. Thereby, the motivations are strongly affected by economic considerations, initially focusing on the avoidance of costs for disposal or storage. "Peels and scraps are 50% of the total production volume. This is due to the special peeling process. And these streams have to be handled somehow" (interview company 3). From this point of departure ('somehow dealing with by-products'), the four potato processors developed individual strategies of by-product valorisation, which gradually led to more or less sophisticated CEBMs, as described and illustrated above. It is important to note that these approaches involved a shift in the firms' assessment of by-products from a kind of burden to a multi-faceted resource that may contribute to certain added-value. Therefore, livestock feeding and bioenergy production have proven appropriate and quite comfortable solutions, even though their added-value potential is rather limited.

A more ambitious CEBM has been designed by company 1, relying on differentiated valorisation pathways to optimise the revenues generated from by-products. For example, the company produces high-quality fertilisers from potato pulp after digestion in the firm's own biogas plant. The conversion of the organic material results from a specialised drying procedure, before the fertilisers are profitably exported to Italy. In addition, company 1 focuses on the extraction of potato starch during the production process, which is then sold to national and international starch processors. Even the use for livestock feeding has been optimised, as the by-products are cooked in a special unit to prepare them for the pig sector. Due to these practices of cascading and repurposing, while depending on further processing of by-products, the company is able to better exploit the economic potential of by-products and to situate its CEBM on a broader (by-)product base. In this context, the large size and related resources (financial, personnel, know-how) of company 1 are certainly advantageous. Another example of a more sophisticated CEBM is that of company 3, which is primarily focused on valorising by-products 'in-house'. The

motivation behind this approach is described by the interviewee as follows:

"At the beginning, the peels were regarded as waste without any value. But then there was a period, in which grain-based feed became more and more expensive, and many livestock farmers switched to potato peels or other waste materials. The demand increased and prices as well. That was the tipping point" (interview company 3).

This quote again reveals the shifting economic assessment of potato by-products. Likewise, companies 2 and 4 emphasised economic issues as the main enabler for developing and refining their CEBMs.³ While company 1 and especially company 3 have meanwhile created viable internal solutions for by-product valorisation (biogas plants, pig barns), companies 2 and 4 rely on the collaboration with external partners for cascading, repurposing or organic feedstock conversion.

Another enabler explicitly mentioned by three of the four interview partners is the growing importance of sustainability and corporate responsibility. Hence, companies 1 and 2 have recently published their first sustainability reports, with circular resource and energy flows playing a major role in each case. The pursuit of sustainability goals also applies to companies 3 and 4, as shown, for example, by respective announcements on their corporate websites. However, the firms' understanding of sustainability and its connection to their CEBMs is not always clear. It seems that CE activities are rather driven by optimising resource and material use, while simultaneously saving costs, rather than by environmental or even social issues. The following quote found in the sustainability report of company 2 (under the heading 'concepts of sustainable resource management') discloses the firm's motivation in a disclosing manner:

"Following the principles of lean management, our aim is to identify and eliminate wastefulness. In this context, wastefulness includes all meaningless and unnecessary activities that do not contribute to increasing product value. Of course, we can not completely avoid all non-value-added activities, but we can seek to reduce them to a minimum" (excerpt from the sustainability report of company 2).

The strong economic focus expressed here gives cause to critically discuss the sustainability idea of company 2. A narrow concept of sustainability is also adopted by company 1, whose CEBM mainly follows the logics of resource

³ Nevertheless, it has to be noted that the economic value of potato by-products is still significantly lower compared to other plant-based industries, such as rapeseed or sugar beet production.

efficiency and optimised material flows. Here again, the economic dimension of sustainability obviously stands out, even though the company addresses environmental and social issues as well by generating renewable energy from by-products and feeding it into the local heat grid at municipality level (probably not without economic motives). The latter is also true for company 3, providing bioenergy for the home village of the company. By contrast, the intention of company 4 is a little different. In conjunction with its clear niche orientation, sustainability issues have been the core of the firm's philosophy from the beginning. This is reflected by resource-saving production (including the processing of peels), short supply chains and local engagement. "We try to protect nature and resources in an economically feasible way. (...) In the medium-term, we will probably launch an organic product line" (interview company 4). Apart from that, the economic importance of by-products, i.e. waste oil, has only recently gained momentum. Fostered by environmental policies, plant-based waste oils have become a preferred input material for diesel production, leading to rising demand by the fuel industry, with increasing prices as well. Due to this side-effect of a political decision, the firm has begun to deal more seriously with by-product valorisation and purposive CEBM design. This company exemplarily demonstrates the impact of institutional context conditions, which are further scrutinised in the next section.

Contextualising CEBMs—the political and economic environment

Both policy and the volatility of markets have a noticeable impact on CEBMs in the potato industry. One of the most influential policy measures was the [introduction](#) of the German Renewable Energy Sources Act (EEG)⁴ in the year 2000. This legislation induced a real 'biogas boom' in Germany during the 2000s, especially after its first amendment in 2004. As a result, many biogas plants were built especially in western Lower Saxony, where spatial conditions had been very advantageous for the production of bioenergy. The first amendment of the EEG in 2004 included a bonus for energy generated from renewable raw materials (NaWaRo⁵ bonus), which provided a strong incentive for potato farmers and processors to utilise their by-products for biogas production. Companies 1 and 3 made use of this opportunity through the installation of their own biogas plants, thereby creating an internal process of resource and energy circulation. "Actually, we only got on the right track in 2004, when the EEG was modified by providing the NaWaRo bonus. Only then,

it became financially attractive to some extent" (interview company 3). This quotation underscores the importance of the German energy policy for the functioning of CEBMs in the potato industry (as in many other industries) and, simultaneously, the reduction of biomass to be disposed. This form of bioenergy produced from by-products is regarded as 'more' sustainable, as it does not depend on energy from plants, as in the case of maize or rapeseed.

Policy also significantly affected company 4 and its valorisation of waste oil for the production of biofuels. In the last two decades, the biofuel industry has been strongly promoted by a number of policies at EU and national levels. In Germany, the Biofuel Sustainability Ordinance⁶ introduced in 2009 is of particular relevance. The regulation is legally based on the Federal Energy Tax Act and the Federal Emission Control Act. In combination, both policy frameworks set the rules to support biofuels especially made from waste oils, as these do not directly contribute to land use conflicts ('food or fuels'). The waste oil of company 4 is collected by specialised oil processors from Hamburg, Munich and Münster. These firms are able to transform the oil into biofuel through microfiltration and settling processes. The interview partner of company 4 describes this form of repurposing in more detail:

"Our specific frying procedure is somewhat disadvantageous. Starch and other substances flow into the oil, which accelerates its maturing process. As a result, we produce more waste oil than conventional fries or chips producers. It is our most important by-product stream, and we sell it to three oil processors. (...) At this point, policy comes into play, since old plant-based oils are favoured ingredients for bio-diesel, making it even more profitable for us. At the beginning, the price was 40 cent per kilogram; now it is 70 cent. (...) The processors usually collect the oil by themselves, before preparing it for the biofuel industry" (interview company 4).

Besides policy and legislation, macro-economic conditions also affect the valorisation of by-products in CEBMs. As already mentioned above, the demand for by-products by livestock farmers partly depends on price developments in the feed market. When feed prices are rising, for example, due to market volatilities that may affect grain-based ingredients of compound feed, there is often additional demand from the livestock farming sector. This demand is an important vehicle to gain certain added value, but requires flexibility in responding to changing market conditions and demands. To achieve this, potato processors do

⁴ In German: Erneuerbare-Energien-Gesetz (EEG).

⁵ NaWaRo stands for 'Nachwachsende Rohstoffe' (renewable raw materials).

⁶ In German: Biokraftstoff-Nachhaltigkeitsverordnung (Biokraftstoff-NachV).

not necessarily rely on a single valorisation pathway, but rather pursue different options: “First of all, we try to minimise our by-product streams or to make anything else from them. Only then, we will focus on animal feed, while the last option is biogas” (interview company 2). The interviewee points to a kind of hierarchy that defines the firm’s CEBM, while the different pathways are at least indirectly shaped by institutional context conditions. With regard to internal biogas production through the firm’s own water treatment plant, the interview partner further argues that “policy regularly compels us to do a lot of different things. For example, energy: After these political decisions, we decided to build the plant, and now we are almost self-sufficient. Heat completely, electricity 90%” (interview company 2).

Another issue related to the institutional context is the emerging discourse on sustainable food production. While sustainability principles have increasingly become institutionalised through standards and certifications (e.g. GlobalGAP, RSPO⁷), the interview partners (including the whole sample of 28 interviews) mainly acknowledge their importance, though differing significantly in terms of perception and practical implementation. Some interview partners are even very critical on the role of sustainability in the potato sector. For example, a potato breeder argues that sustainability is “merely a marketing thing”, and an agronomist regards it as “a means to put pressure on the [value] chain”. Even when it comes to organic potatoes, the viewpoints are quite different, ranging from “an emerging topic we will focus on in the mid-term” (interview potato processor) to “organic farming is nothing but ‘whitewashing’” (interview potato trader). By contrast, the handling of waste and by-products and the closing of biological resource cycles are rather specific issues that particularly affect the larger potato processors. Accordingly, the companies 1 and 2 from our case study sample feel to be under growing pressure from discourses on resource efficiency and food waste that are increasingly fuelled by specific interest groups and public authorities. Both firms decided to proactively deal with these issues and made them an integral part of their corporate strategy. For example, company 1 strives for closing resource cycles along with a ‘no waste’ philosophy:

“Time and again, we are faced with the question of how to close this production cycle. (...). We will be prepared to process all the raw materials coming in. This is, of course, due to the political background, political issues that we will have to deal with. (...). But already today, we are able to use everything. There is nothing to be disposed of or wasted” (interview company 1).

Company 2 also seeks to prevent the occurrence of by-products, but has only partially succeeded so far. Therefore, the firm has recently introduced a new programme called ‘Pro2025’ to optimise processes and resources, while simultaneously avoiding wastage. According to the interviewee, this is “another cornerstone of our corporate strategy, following the three pillars of sustainability” (interview company 2).

In sum, our findings illustrate that the implementation of CEBMs based on by-product valorisation results from a complex interplay of internal and external enablers, with economic considerations as the main impetus. A striking feature is the economic reassessment of by-product streams ‘from waste to value’, meanwhile playing a significant role in the value creation processes of potato firms. Some of them promote the valorisation of waste and by-products as part of their sustainability strategy by emphasising circularity, resource-efficiency and eco-friendliness. These side-effects may also contribute to a positive image of the firms in question, though not being explicitly mentioned during the interviews.

Discussion

Circular agri-food economies mostly aim at improving the efficiency and recycling capacity of current production-consumption relations through development, restructuring and combination of biological reverse cycles. According to the EMF (2015) and Lüdeke-Freund et al. (2019), these cycles include cascading and repurposing (e.g. livestock feed, fertilisers) as well as organic feedstock conversion (e.g. bioenergy), which were both found in the potato sector. Large amounts of organic waste and by-products particularly occur at the processing stage, requiring potato processors to develop tailor-made CEBMs. These either rely on partnerships with external actors (e.g. livestock farmers, biogas producers, waste oil preparators) or involve the creation of reverse cycles ‘in-house’. Against this background, the findings raise a number of issues worth being discussed in more detail, and in relation to other studies on circular (bio) economies and resource management.

First, the design and refinement of CEBMs follows from a shifting economic logic in the assessment of potato by-products. For a long time, these organic materials have been mostly treated as waste to be disposed of. Only around the year 2000, the utilisation of by-products became increasingly important, which was triggered by supporting policies on renewable energies, changing feeding practices in livestock farming, and further developments in the emerging field of the bioeconomy (e.g. organic fertilisation, biofuels). This political and economic environment in a sense opened up a ‘window of opportunity’, while shedding new light on the valuation of biomass and organic waste. Therefore, many

⁷ Roundtable on Sustainable Palm Oil.

potato farmers and processors decided to put a stronger focus on circular resource flows, and redesigned their business models by incorporating practices of cascading, repurposing and/or feedstock conversion. These findings are in line with those by Perey et al. (2018) who analysed different business models that result from a reconceptualisation of waste streams. More precisely, the authors identified multiple practices of waste valorisation within a burden-resource continuum, which “highlights a tension in business model design between linear logic applied to a business process where waste is understood to be a burden and therefore needs to be eliminated materially and where waste, reframed as a resource, is now understood to have value as an input into a new process” (Perey et al. 2018, p. 635). An additional insight of our analysis refers to the flexible advancement of CEBMs in response to changing institutional and market conditions that, in turn, affect the revaluation of by-products. This may especially provoke rethinking the use of by-products for energy production. By contrast to other contributions questioning their (energetic) value potential (especially those referring to the ‘food waste hierarchy’, e.g. Papargyropoulou et al. 2014; Teigiserova et al. 2020), our analysis reveals a different perspective in which bioenergy is regarded a quite promising pathway for by-product valorisation in circular systems. This angle does not primarily include monetary revenues, but environmental and societal issues as well, while also reflecting on the negative externalities related with ‘conventional’ bioenergy produced from plants.

Second, more ambitious valorisation pathways require particular knowledges, technologies and infrastructures. The example of the high-quality fertiliser extracted from potato pulp by company 1 not only depends on anaerobic digestion in the firm’s own biogas plant, but also involves a specific drying process of the residues, which are then further transformed into either pellets or granular materials. Such processes may give rise to rethink the importance of organic feedstock business models, whose value creation potential is considered rather limited so far, not going beyond “their ability to support the processing of organic waste that can then be used as production inputs or safely disposed of into the biosphere” (Lüdeke-Freund et al. 2019, p. 53). In this specific case, it may be appropriate to speak of ‘upcycling organic feedstocks’, as the fertilisers are successfully distributed to customers from Italy. Another example for larger investments into new technologies and facilities is the expansion of company 3 into the pig farming sector, including the construction of three pig barns and a large-scale cooking plant to prepare the potato peels for pig feeding. While this company also operates two biogas plants, it has designed a very exceptional CEBM combining three different activities (food processing, livestock farming, bioenergy production) under one umbrella. Thereby, the company benefited from

the broad agricultural experience of its founding members, i.e. ten local farmers.

Third, business model innovations that aim at more radical transformations in the organisational or systemic ‘architecture’ of the companies could not be found. Even though many ambitious efforts were made for integrating circular resource flows into the firms’ business models, there is no evidence for disruptive approaches to create completely new CE pathways. This observation confirms D’Amato et al.’s (2020) analysis on forest-based CEBMs in a Finnish context, where the companies studied “appeared to be strongly dominated by traditional practices (e.g. use of renewables, efficiency). On the other hand, more avant-garde perspectives were missing in the business models analyzed, such as promoting frugality, reducing materiality, securing livelihoods and/or supporting natural systems” (D’Amato et al. 2020, p. 8). It has to be noted that such ‘avant-garde perspectives’ are not an end in themselves, but have the potential to address some core problems suggesting the need of CEBMs, as they especially question the growth paradigm and its inherent logic of ‘take-make-consume-dispose’ (Hobson and Lynch 2016; Schulz et al. 2019). For the potato industry, this could mean to find possibilities for reducing by-products in general, which however will require food retailers (and consumers as well) to rethink their behavior regarding product range, standards, and the availability of food. Another aspect we found in relation to business model innovations is a widespread absence of higher-added-value activities in CEBMs. These may include the use of by-products for special food ingredients (e.g. enzymes, aromas), pharmaceuticals or biochemicals, which are quite well-developed in other plant-based agri-food sectors (e.g. De Corato et al. 2018; Schieber 2017). According to the interviewees, such activities do not yet play any role in the potato sector due to either a lack of knowledge or missing capacities. This finding is similar to that of Donner and de Vries (2021, p. 11) who argue that “within the domain of agricultural waste valorisation, technological developments at least for high-value adding conversion pathways are still ongoing and often not yet in mature stages or asking for scaling-up”.

While reinforcing and expanding the results of relevant studies, this paper also brought some new insights on the functioning of biological reverse cycles in CEBMs, representing the ‘left wing’ of the well-known ‘butterfly diagram’ (EMF 2015). In particular, the in-depth study of four potato processors has drawn a clearer picture on CEBMs in plant-based industries with a special focus on practical implementation, enablers and motivations, and institutional settings. In doing so, the paper goes beyond the majority of academic literature exploring circular (bio)economies and waste valorisation from a technological or natural sciences perspective. It has been shown that the management of circular resource flows at firm-level is directly linked with a

shifting economic assessment of by-products, accompanied by far-reaching policy incentive schemes such as the Renewable Energy Sources Act (EEG). More recently, however, especially the larger companies feel increasingly affected by the public discourse on sustainability, prompting them to (re) design their CEBMs based on a more advanced understanding of waste and by-product streams in view of environmental and societal issues.

Conclusions

In this paper, we explored the practical implementation of CEBMs using potato production in Lower Saxony (north-west Germany) as an illustrative example. Inspired by conceptual thoughts on biological resource flows in CEs, we conducted a case study-based analysis of different companies to shed light on the valorisation of by-products as the main pillar of CEBMs. More specifically, we sought to understand the underlying practices and relations, the main enablers and motives, and the impact of institutional context conditions (policies, markets). The findings revealed, among others, that CEBMs are motivated by the necessity to somehow deal with the large amounts of potato by-products in conjunction with a gradual reassessment of their economic value, and further driven externally by policy incentives, market dynamics, and emerging discourses on sustainable food production. The implementation of CEBMs mostly relies on (less formal) partnerships with different actors of the agribusiness (e.g. livestock farmers, biogas producers, feed companies), while some companies – both larger and smaller ones – have built up their own structures for internal processing of by-products.

These findings may partly satisfy recent appeals by Donner et al. (2020), Lüdeke-Freund et al. (2019) or Velenturf et al. (2019) who suggest to explore circular economies more holistically in consideration of socio-economic issues. However, there is still much to be done to fully understand the functioning and impact of circular agri-food economies, as they encompass technological, economic, environmental, societal and political domains. For example, there is a lack of research on the role of public sustainability discourses in shaping CEBMs. How do critical debates around food waste, resource shortage, oversupply etc. affect the corporate strategy of agri-food companies? How are respective pressures channelled through the value chain ('from fork to farm')? And what is the role of power imbalances in that respect? Another research avenue might address the transformative capacity and sustainability outcomes of circular agri-food economies, with life-cycle analyses (LCAs) critically reflecting upon (potential) negative externalities across businesses and/or economic sectors. Assessing the transformative capacity of CEs also requires a closer look at the demand

side and the (un)willingness of people to change their consumption practices. Dealing with these questions may offer fruitful response to recent appeals by Hobson and Lynch (2016) or Schulz et al. (2019) to overcome the limitations of sector-, material- or technology-oriented CE concepts. Finally, future research might explore whether organic waste from bio-based industries can be directed into more innovative forms of valorisation (e.g. 'smart materials', pharmaceuticals), and how respective ambitions will affect the 'architecture' of existing CEBMs. Apart from this, we argue for dealing more explicitly with notions of 'upcycling' (instead of 'recycling') in debates around circular (bio)economies.

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