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Innovation and by-product valorization: A comparative analysis of the absorptive capacity of food processing firms

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A B S T R A C T

The transition toward the bioeconomy concerns how firms innovate, especially how they utilize bio-based resources. This qualitative study explores how incumbent firms in a low-tech industry like food make use of technological developments to create high added-value for their by-products. The paper compares managerial efforts to utilize biotechnology in a meat and a dairy firm in the Norwegian food processing industry. The theoretical approach draws on the concept of absorptive capacity from organizational learning literature and innovation studies. The study finds that firms in the same industry with quite similar structures (i.e. the form of ownership) can nevertheless pursue divergent strategies toward developing innovations for by-product utilization. Through the process of learning, the study notes the role of firms' absorptive capacity—exploratory, transformative, and exploitative—in acquiring external knowledge, experimenting with the newly acquired knowledge, and mobilizing necessary resources to adopt and develop technological innovations during the transition process. The study highlights the importance of inter-industry learning and research collaboration, market understanding, and supportive policies and regulations in fostering a bioeconomy.

1. Introduction

The bioeconomy requires a total transformation of the entire economy from fossil-based production and consumption to bio-based production and consumption (European Commission, 2012). This transformation calls for engagement, commitment, and action from major stakeholders in the economy, especially in the matter of resource efficiency (Ekins and Hughes, 2016; European Commission, 2011). Key players such as industrial firms are the subject of an ongoing debate about how they go about utilizing their bio-based resources in order to generate economic value with the least environmental impact (Boons and Lüdeke-Freund, 2013; De Besi and McCormick, 2015; Zhou et al., 2018). The food industry is often criticized for wasting raw materials (European Commission, 2014); especially when those resources could offer added-value in a variety of applications and products through bioprocessing technologies (Henchion et al., 2016; Lynch et al., 2017; Toldrá et al., 2016). Yet, there is no one formula for the valorization of organic waste and by-products since different technologies are used for different types of by-products (Demirbas, 2011). The choice of technology depends on the type, quality and volume of the materials, and on the local conditions where the raw materials are sourced (Lin et al., 2013). Nonetheless, the value chain of food by-product valorization—from by-product sources and input to potentially commercial products—is under-addressed in innovation studies (Carraresi et al., 2018; Reardon et al., 2017; Wensing et al., 2019). We lack an understanding of how incumbent firms[1] innovate in the era of transition toward the bioeconomy.

Further, notwithstanding increasing research activity in the field of sustainability transitions, our understanding of the dynamic role of actors involved in innovation and transition processes remains limited (Farla et al., 2012; Markard et al., 2012). More specifically, there is a sparsity of studies looking into how strategies, resources, and capabilities of firms and organizations impact and trigger the transformation processes (Farla et al., 2012). Transition studies have not devoted much attention to this layer of complexity inside firms (Geels, 2014). Thus, more micro-level studies on "what strategies … actors adopt to shape sustainability transitions and what resources

[1] An incumbent firm is defined as one that has already established a position in a market (Black et al., 2009).

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… they mobilize and deploy in the realization of these strategies" (Farla et al., 2012, p. 992) are needed to untwist some of the complexities of transitions.

To understand how incumbent firms develop innovations, strategic management literature emphasizes the role of knowledge development and transfer within and across firms (Grant, 1996; Leonard-Barton, 1995; Nonaka, 1994; Pisano, 1994; Roy and Sarkar, 2016; Spender and Grant, 1996). Absorptive capacity is a seminal management concept that seeks to understand how firms acquire and utilize external knowledge in order to generate innovations (Cohen and Levinthal, 1990; Easterby-Smith et al., 2008; Lane et al., 2006; Murovec and Prodan, 2009; Todorova and Durisin, 2007; van den Bosch et al., 2003; Zahra and George, 2002). Despite being frequently cited, absorptive capacity as a process or capability (Edmondson and McManus, 2007) has limited empirical evidence behind it and unverified assumptions (Patterson and Ambrosini, 2015). More qualitative studies on the operationalization and testing the assimilation and/or application of external knowledge in empirical contexts will illuminate the underlying process structures and dynamic nature of absorptive capacity (Easterby-Smith et al., 2008; Jiménez-Barrionuevo et al., 2011; Lane et al., 2006; Volberda et al., 2010).

In view of this, the paper strives to fill in such gaps by tackling the following research question: *What is the role of absorptive capacity in incumbent firms' adoption, development, and valuation of technological innovations for sustainability transitions*? The study aims to explore how incumbent firms make use of technological developments to develop internal innovations as part of the transition toward a sustainable bioeconomy. I seek a better understanding of the interrelationship between incumbents' absorptive capacity and the way they build up their knowledge base of technological innovations to create higher added-value for their by-product and side stream resources. In particular, the paper carries out a comparative analysis of two empirical case studies—examining the management process in the utilization of enzymatic hydrolysis of protein technology[2] in a meat and a dairy firm in the Norwegian food processing industry.

The theoretical approach of this paper draws on the idea of absorptive capacity—found in management literature and innovation studies—in order to understand how incumbent food firms appreciate technological opportunities and develop by-product innovations. The paper explores the underlying process of adopting and making use of the technological development (i.e. enzymatic hydrolysis of protein) in the two firms. With insights from the absorptive capacity literature, the paper delves into the firms' ability to capture external knowledge about the enzymatic hydrolysis technology and investigates how they go about transforming the acquired knowledge into innovation (i.e. new products and applications). In other words, the paper scrutinizes firms' innovation process by looking into the incumbents' learning process—exploratory, transformative and exploitative—in relation to such important organizational domains as knowledge development, entrepreneurial experimentation, and resource mobilization. By employing a qualitative research design with open-ended and semi-structured interviews, the paper aims to undertake an in-depth analysis of the actors (the firms) with regard to by-product valorization.

The choice of the case studies—the food processing industry—is made for several reasons. First, the rapid growth of the world's population entails an increased demand for food and food ingredients, which, in turn, requires resource efficient delivery and better utilization of raw materials (Ekman et al., 2013; Garnett, 2013; Henningsson et al., 2004). Second, the significant volume of food wastes, by-products, and side streams generated is matched by the potential of those resources for high value-added products and applications in various fields such as medicine, pharmaceuticals, cosmetics and foodstuffs, thanks to heterogeneous bioconversion technologies (Egelyng et al., 2017; Lin et al., 2013; Mullen et al., 2017; Prazeres et al., 2012). This challenges the food industry to re-examine all processing streams to increase value. However, there is a dearth of empirical studies on specific types of food wastes and by-products, and how industrial firms in the food industry innovate in this area. Therefore, this paper aims at gaining more empirical knowledge by examining the Norwegian food processing industry and adding to the restricted portfolio of empirical research on incumbent firms in low-tech industries. The study attempts to inform policy-makers of the relevant policy aspects of the bio-based economy and industrial firms of the importance of developing their absorptive capacity.

The paper is structured as follows. Section 2 puts forward the theoretical foundation of the study. Section 3 introduces the methods and data and the empirical case study—the Norwegian food processing industry and the two incumbent firms. Section 4 presents the results while Section 5 turns to discussion of the analysis. Section 6 marks the conclusion and outlines the policy implications and potential for further research.

2. Theoretical approach

2.1. Incumbent firms and technological innovations

The emergence of new technologies and socio-technical transformation greatly affects the positions and strategic interests of incumbents and newcomers (Grin, 2010). The debate on incumbent firms in the face of technological challenges commonly discusses the firms' failure to embrace new technologies (see, e.g., Ansari and Krop, 2012; Bergek et al., 2013; Chandy and Tellis, 2000; Dewald and Achternbosch, 2015; Hill and Rothaermel, 2003). Explanations for this failure are inertia within the firms, the embeddedness of established systems (infrastructure and industry networks), and possibly low economic incentives, which dissuade the incumbents from initially valuing the new technology (Hill and Rothaermel, 2003). Nevertheless, incumbents also have an advantage over new entrants or challengers in terms of better access to complementary assets, enabling them to benefit from the innovation and buffer from the competition (Ansari and Krop, 2012).

In relation to the bioeconomy, by studying the value chain of the case of phosphate, Carraresi et al. (2018) expound on the hesitation of chain actors to make new investments in equipment and new knowledge, their lack of complementary competencies, and the difficulties they experience in integrating divergent industrial sectors in cross-industry innovation. This can be explained by the fact that chain actors encounter numerous challenges associated with the adoption of novel processing technologies, such as high switching costs, a lack of quality standards and industry standards, as well as inadequate existing regulatory frameworks.

Despite recognition of the important role of firms in generating, diffusing, and utilizing technological innovations, we lack an understanding of why and how some incumbent firms engage in technological innovation in the first place (Safarzyńska et al., 2012), as well as of the underlying processes and mechanisms at work. One central critique is that transition studies pay little attention to the importance of agency (Markard et al., 2012). Thus, an *actor-oriented* approach is put forward to better understand the micro-

[2] Enzymatic hydrolysis of protein is a process using enzymes to facilitate the separation of peptide bonds for the development of protein hydrolysates (Tavano, 2013). Protein hydrolysates (or hydrolyzed proteins) are the output products of this process.

level foundation of innovation (Markard and Truffer, 2008). To grasp the underlying dynamics of actors in technological innovation, transition scholars have used concepts in the strategic management literature in order to direct attention to various micro-level processes, such as network building and the formation of coalitions, shaping expectations, or market creation (Dewald and Truffer, 2011; Musiolik and Markard, 2011; Musiolik et al., 2012). From a conceptual point of view, this approach has the potential to explore the boundary area, where the two strands of literature might be “fruitfully related to each other” (Markard and Truffer, 2008, p. 444). For instance, a micro-level study of firms in the biomedical clusters of Ohio and Sweden by Cetindamar and Laage-Hellman (2002) notes the importance of firms’ production and technology competencies, technology transfer capabilities, and commercialization strength during technological transformations.

2.2. Absorptive capacity and organizational learning

Knowledge represents a vital resource for firms to create value, develop innovations, and sustain competitive advantages, especially in a dynamic and turbulent environment (Teece et al., 1997). Outside sources of knowledge are often crucial to the innovation process, thus “the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends is critical to its innovative capabilities” (Cohen and Levinthal, 1990, p. 128). This absorptive capacity (hereafter ACAP) is a prevalent concept originally developed by Cohen and Levinthal (1989), whereby the authors stress the ability of firms first acquire external knowledge, assimilate it, and later exploit it. Hence, the process of absorbing external knowledge becomes a pivotal factor in firms’ innovation and adaption to change in a competitive environment (Camisón and Forés, 2010).

However, the process nature of the relationship between ACAP and organizational learning, i.e. how ACAP affects knowledge creation within an organization and helps assimilate and integrate external knowledge with existing knowledge, has not been studied extensively in the management literature (Lane et al., 2006). To develop further the ACAP constructs in relation to the organizational learning, Lane et al. (2006) expound a three-stage sequential process: *Exploratory learning, transformative learning, and exploitative learning*. Exploratory learning is the ability to recognize and understand potentially valuable new knowledge outside the firm. Transformative learning is the ability to assimilate valuable newly explored knowledge. Lastly, exploitative learning refers to the ability to apply the assimilated knowledge to create new knowledge and commercial outputs. Firm strategies are important in driving the focus of recognition and understanding, assimilating, and applying external knowledge. Direct outputs are new knowledge (general, scientific, technical, and organizational) and new products and services. Further outcomes are firms’ long-term performance and value creation (Cohen and Levinthal, 1990; Lane et al., 2006).

The main resulting question regarding the organizational learning of firms is: *What do firms learn*? Through an extensive literature review of ACAP, Lane et al. (2006) summarize three major external knowledge types that organizations acquire: Knowledge content, knowledge ‘tacitness’, and knowledge complexity. Knowledge content or “know-what” refers to a specific kind of knowledge such as new technologies, customers, markets, and common skills (Bierly and Chakrabarti, 1999; Lane and Lubatkin, 1998). Similar culture and cognitive structures are likely to enhance knowledge absorption and assimilation (Bhagat et al., 2002; Simonin, 1999). Knowledge ‘tacitness’ or “know-how” refers to the extent to which the knowledge consists of implicit, ambiguous, and non-codifiable skills (Kogut and Zander, 1992; Lam, 1997; Nonaka, 1994). This type of knowledge embeds in complex processes, interactions and routines within the firm; it is thus difficult to transfer and absorb (Saviotti, 1998; Simonin, 1999; Szulanski, 1996), which consequently can create barriers to innovation (Reed and DeFillippi, 1990; Simonin, 1999). Knowledge complexity refers to a variety of interdependent technologies, routines, individuals, and resources associated with a particular knowledge or asset (Simonin, 1999). The complexity lies in the linkages between different knowledge content areas (Garud and Nayyar, 1994). The more complex the knowledge is, the harder it is for organizations to understand and absorb. Additionally, the complexity of knowledge increases sharply in dynamic environments. Firms in such an environment, in order to increase their ACAP, need to initiate other organizational policies, such as research partnerships (Goes and Park, 1997; Powell et al., 1996; Steensma and Corley, 2000).

For radical technological innovations, all three dimensions of knowledge are likely to be needed. Some scholars have suggested that radical innovations[3] involve a novel combination of existing technologies and know-how (Kogut and Zander, 1992; van den Bosch et al., 1999). However, the underlying process that specifies explicit mechanisms for integration and exploiting such loosely related domains has been relatively under-examined (Lane et al., 2006). In other words, there has been little attempt to study the relationship between ACAP and radical innovation (Lane et al., 2006). Since the majority of ACAP research has focused on R&D and patents (see among others, Cohen and Levinthal, 1990; Meeus et al., 2001; Mowery et al., 1996), this leads to an over-emphasis on understanding the technological or scientific knowledge (i.e. the knowledge content) the firm needs to acquire, at the expense of comprehending the *process knowledge* needed to assimilate and apply it (Lane et al., 2006; Patterson and Ambrosini, 2015). This demonstrates the importance of future empirical studies achieving a deeper analysis of intra- and inter-organizational aspects of ACAP at the micro-level (Volberda et al., 2010). Moreover, as ACAP strengthens the role of outside knowledge to firms’ innovation, it should not only be studied in terms of R&D expenditure or patents (Patterson and Ambrosini, 2015). ACAP—as a dynamic capability—is pertinent to any external strategic factor, such as potential market, customer or technical knowledge (Volberda et al., 2010), which can be assimilated and applied to commercial ends.

2.3. Incumbent firms and absorptive capacity

Because of its crucial role in firms’ innovation and learning, ACAP is needed for all types of organizations. The assumption of absorptive capacity suggests that incumbent firms may find it challenging to accumulate the new knowledge underlying a radical innovation if that knowledge falls outside of their expertise (Hill and Rothaermel, 2003). Therefore, when an incumbent lacks sufficient relevant prior knowledge and wishes to acquire and use knowledge unrelated to its current activity, it must dedicate effort exclusively to creating absorptive capacity (Cohen and Levinthal, 1990). This is the situation for the two incumbents under study, given that the enzymatic hydrolysis of protein technology was new to them. Thus, ACAP becomes even more critical for firms acquiring new, relevant knowledge if they are to succeed in such a new venture. This paper endeavors to explore critical factors for their involvement, adoption, and utilization of the technology by examining the process of exploratory, transformative, and exploitative learning. Fig. 1 illustrates the analytical framework of this study. Firms view technological developments as potential

[3] Radicalness here refers to how new it is to the firm.

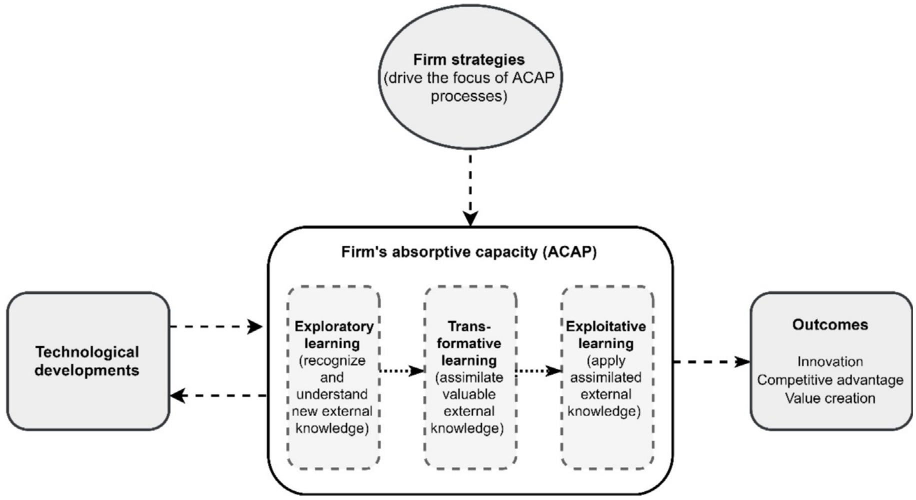


Fig. 1. Incumbent firms and absorptive capacity, author's illustration based on Cohen and Levinthal (1990) and Lane et al. (2006).

acquisitions while considering internal strategies to drive the focus of ACAP. By zooming in micro-level factors and analyzing the ACAP processes, this study uncovers firms' innovation process and strategic decisions in the face of technological changes and contributes to a better understanding of innovation dynamics at the organizational level during sustainability transitions.

3. Methods, data, and the case

3.1. Methods and data

This paper applied a qualitative research design and undertook a comparative case study (George and Bennett, 2005; Yin, 2014). The primary data was based on 17 interviews in the period from 2016 to 2019 with the two firms, i.e. the dairy and the meat firm, and other stakeholders in the Norwegian food industry including research institutes, policymakers, rendering firms, industry experts, an industry association and a confederation, and government officials. A list of interviews is provided in Table A1 in the Appendix. This study employed a two-stage interview process. The first round of interview was based on a by-product value chain with questions covering various stages—from raw materials input, processing, transportation and distribution, to retail (see the interview guide in Table A2 in the Appendix). I obtained a general understanding of the firms' current situation concerning by-products and organic waste valorization and discussed potential technologies as well as their needs, interests, and strategies. In the second round of interviews, I went deeper into comprehending a technology that the firms were particularly interested in—enzymatic hydrolysis of protein—and studied their managerial efforts in acquiring this based on the process of learning and the ACAP concept (see the interview guide in Table A3 in the Appendix). The interviews were recorded and transcribed. Summaries of the interviews were written and sent back to the interviewees for clarification and to avoid misinterpretation.

The choice of qualitative research design, using a semi-structured and open-ended interview method, aimed at achieving an in-depth and thorough understanding of the firms' strategies in respect of developing innovations for their dairy and animal by-product valorization. Another important reason for choosing this approach was to respond specifically to the call by Patterson and Ambrosini (2015) for qualitative data around firms' absorptive capacity. The primary benefit of qualitative data is that it can help "expose evidence for the ACAP constructs in a way that 'black box' quantitative approaches cannot" (Patterson and Ambrosini, 2015, p. 80).

However, the potential drawback of the interview-based case studies method is that the findings may not be generalizable to other contexts, and interviewees' opinions can sometimes be biased. Thus, to gain multifaceted views, I interviewed not only the two firms but also other actors in the industry (see Table A1 in the Appendix). Further, in order to triangulate the qualitative data, one important secondary source of data for this study was gathered from the project database of the Research Council of Norway. This quantitative data provided an overview of the research projects that the two firms were involved in, which was important in mapping the types of knowledge and information the firms wanted to acquire for this specific enzymatic hydrolysis technology. To further supplement the analysis, other sources of data were assembled, e.g. government documents, white papers, and reports. Based on the collected data, a comparative case study of the two firms was carried out.

3.2. Case: The meat and the dairy firm

The Norwegian food industry plays a key role in the country's economy as it is the largest mainland manufacturing industry by turnover, value creation, and number of employees (Prestegard et al., 2017). The two firms were selected because they are the biggest food processing players in Norway, thus it was deemed relevant to look at the firms' strategies in utilizing their abundant by-product resources. *The dairy firm*[4] is a big dairy firm, cooperatively owned by farmers in Norway with a turnover of USD 2513 million and USD 168 million in operating profit, 5355 employees, producing various dairy products for the Norwegian and international markets. The firm's organic by-products and residues include cheese whey, buttermilk, cheese dust, wasted milk and disqualified cheese products. Two types of whey are generated at the firm. Sweet whey comes from white hard cheese production with a volume of 25 000 tons a year whilst acid whey is a by-product of cottage cheese production and Greek yogurt with a volume of 1000 tons a year (but increasing rapidly due to the demand for Greek

[4] Information about the firm in this section is obtained from its 2018 annual report.

Table 1
By-products and organic wastes and current processes of the dairy firm.

Type of wastes, residues, and by-products	(Final) markets and/or current solutions
Sweet whey	Whey powder and whey permeate powder used in different ingredients/products
Sour (or acid) whey	Feed (pigs and cattle), energy, and in fermentation processes
Buttermilk, other dairy wastes	Ingredients in human products and animal feed
Sewage sludge	Energy

yogurt products). Current solutions and markets for the dairy firm's by-products and organic wastes are described in Table 1. *The meat firm*[5] is a large meat and egg firm, also cooperatively owned by farmers in Norway with a turnover of USD 2563 million and 5000 employees, providing meat and egg products mainly for the Norwegian market. Animal by-products generated at the firm are hides and skins, feather, organs, fats, bones, blood, intestines, internal parts etc., which are approximately 150 000 tons a year. Table 2 elucidates current solutions and markets for the meat firm's by-products and organic wastes.

Both dairy and meat by-products and side streams are great sources for potential bioconversions (Lin et al., 2013). The enzymatic hydrolysis of protein (hereafter PEH) is a bioconversion technology that works well on dairy and meat by-products since they are both protein-rich (Krasnoshtanova, 2010; Morais et al., 2013; Spotti et al., 2017; Tavano, 2013). Based on Tables 1 and 2, Fig. 2 illustrates the current processes and potential changes if the enzymatic hydrolysis of protein technology (PEH) is implemented in the two firms.

4. Incumbent firms and the process of learning

This section presents the results of the analysis of the process of learning—exploratory, transformative, and exploitative—in the two incumbent firms. I discuss the process of learning in relation to the three strategic domains of the incumbents: Knowledge development, entrepreneurial experimentation, and resource mobilization.

4.1. Exploratory learning and knowledge development

In the modern economy, knowledge is considered the most fundamental resource and learning the most important process (Lundvall and Johnson, 1994). Knowledge and learning are intertwined such that knowledge development involves a learning process. Knowledge development is a prerequisite for innovation, and thus placed at the center of innovation. Given that by-product valorization is a new business area—and very different from mainstream production—new knowledge development becomes critical for the two incumbents in this study. Firms facilitate the development or diffusion of new technologies by incorporating novel knowledge into their activities; in order to do so, they must have an absorptive capacity (Cohen and Levinthal, 1990).

The exploratory learning phase of ACAP sets out the types of knowledge firms seek and through what channels. For the two firms under study, the enzymatic hydrolysis of protein was a radical innovation—the technology involved methods and materials that were novel to them (Hill and Rothaermel, 2003). Thus, the first type of knowledge they needed to acquire was technical knowledge—knowledge content. As discussed earlier, prior knowledge from the main production did not play a significant role. Utilizing research partnerships to acquire new knowledge was key (Powell et al., 1996). As noted by an interviewee from the meat firm:

> *We have to develop knowledge and know what technologies to invest in, to seek knowledge outside at research institutes. [...] We don't have a very large research department, so we are very dependent on the collaboration with research institutes.*

It turned out that collaboration with research institutes and other industries through R&D projects was crucial for the firms to acquire the necessary knowledge. Table A4 and Table A5 summarize the research projects on PEH by the meat firm and dairy firm respectively. The meat firm acknowledged the enzymatic hydrolysis development by the Norwegian fish industry (Liaset and Espe, 2008; Liaset et al., 2000). It actively searched[6] for more knowledge in the field by participating in projects that involved this industry partner. As one employee of the meat firm remarked about one of the projects:

> *There is much expertise, knowledge in this project*[7]*; not least it has done a lot of good work on fish, which I think we can translate in principle into the meat. Meat, as is known, is very good protein, completely at the height of fish protein.*

The meat firm got in contact with the technology provider who worked with the fish industry and had earlier developed a continuous flow processing technology. This technology had an advantage over the batch processing technology in terms of time, costs, and energy saving. Through the collaborative projects, the meat firm investigated different enzymes and how these enzymes functioned. Additionally, it also learned about various mechanisms of the hydrolysis process and how it worked on different types of rest raw materials, as well as desired outcome products. Table A4 showed a continuous, vigorous effort of the meat firm on studying the PEH technology since 2012. In the projects IV and VII, where the meat firm played the main role as coordinator, it focused intensively on the potential of chicken by-products that were generated at the firm's slaughterhouses in great volume.

For incumbent firms, developing knowledge about new markets is also crucial (Chang et al., 2012; Roy and Sarkar, 2016). However, it was challenging to identify new high value-added niche markets for valorized products since those markets were disparate from the traditional ones and required consumer awareness and willingness to purchase. Although the meat incumbent acknowledged that protein hydrolysates had great potential for various uses and applications, it had to determine which markets (both demographic and geographical) to enter by seeking insights from players in those markets, such as marketing and distributing firms. It had to carefully study health trends and consumer needs and preferences. Apart from proteins for the pet food market, the firm found that protein hydrolysates had great potential in the human consumption market such as in baby and infant food, food for the elderly, and sports nutrition. The US sports market was one target due to its

[5] Information about the firm in this section obtained from its 2018 annual report.

[6] Active searching means firms know in advance what they are looking for and try to find it (Patterson and Ambrosini, 2015).

[7] Project III in Table A4.

Table 2
By-products and organic wastes and current processes of the meat firm.

Type of wastes, residues, and by-products	(Final) markets and/or current solutions
Organs/CAT2 chickens, blood, feathers	Feed to mammal markets (e.g. mink)
Other types of plus products	Flour and fat production to feed ingredients
By-products (intestines)	Pet food, casings
Pork bones (cook bones)	Human food
Fresh meat skins	Gelatin
Organic sludge from slaughterhouse/stomach content	Biogas and composting
Hides/skins	Processed leather and skin products
SRM (Specified Risk Material)	Energy, cement industry
Manure	Composting
Animal fat	Biodiesel
Wool	Clothing, textiles
Other types of organic waste, sludge	Biogas, composting, fertilizer
Eggshells	Composting
Egg products	Swine feed, composting

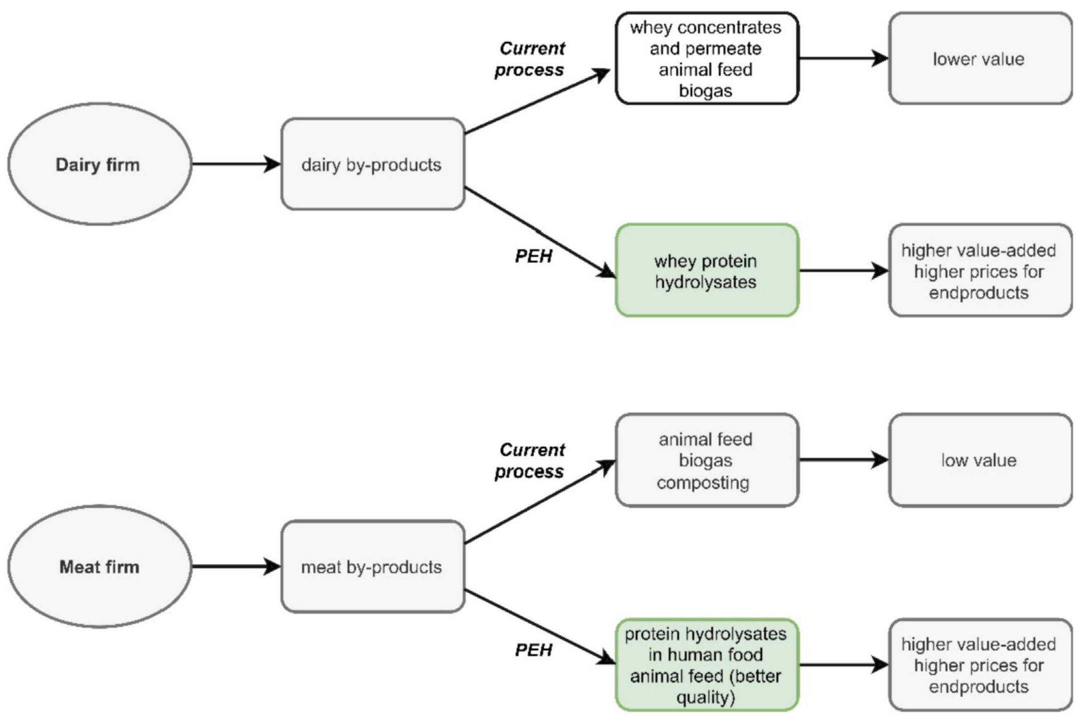


Fig. 2. Current process and potential changes if the enzymatic hydrolysis of technology (PEH) is implemented in the two firms (author's own illustration).

large size (Heitner, 2016). The incumbent's criterion for choosing a market was a good business case with a prospect of profitability:

> *We [the firm] can offer a product that is unique and stands out from alternatives, which fulfills a need and has a long-term competitive advantage.* (Interviewee statement)

The dairy firm, in contrast, started the process of investigating the PEH technology not so long ago, in 2017, when it joined the same project as the meat firm (Table A5). The firm acknowledged the potential of protein hydrolysates from whey but did not have an urgent need to examine this earlier as it produced and sold common whey protein (protein concentrates) by using a drying technology. Like the meat firm, the dairy firm valued the collaboration with the research environment. As one interviewee noted:

> *Working with external research institutes/ research partners is a very important strategy for us as [the firm] has a need to develop and expand its knowledge base. We cannot do everything on our own as we do not have competences in all fields. By using research projects, we can access and develop knowledge and insights from our cooperative network.*

Research projects were a pivotal channel where the two firms 'explored' knowledge about the PEH and its potential for by-product valorization. Research institutes and industry played a role as key partners.

Both firms under study built up their knowledge base through exploratory learning. This absorptive capacity allowed the firms to explore potential knowledge from different learning channels, primarily from collaboration with research institutes, but also taking advantage of knowledge and experience from other industries. The Norwegian fish industry, in particular, played a significant role in the knowledge acquisition of the two firms. The meat firm first acknowledged the Norwegian fish industry's enzymatic hydrolysis of protein process 20 years ago. But, it only started the exploratory process—by participating in an enzymatic hydrolysis research project—in 2012 (project I in Table A5). The dairy firm, by contrast, started to explore the technology by participating in a research project in 2017, although it had earlier acknowledged the potential of protein hydrolysates as its Danish partner produced hydrolyzed proteins on a large scale.

A possible explanation for the difference in the knowledge development strategies of the two firms might lie in the by-product characteristics and external factors such as demand, price fluctuations, and competitiveness. Compared to the dairy by-products, the animal by-products—due to their inherent properties—are more challenging to handle and face stricter regulations of how they should be treated (European Union, 2009; Strøm-Andersen, 2019; Tanner and Strøm-Andersen, 2019). Thus, finding an optimal technological solution was pivotal for the meat firm. Furthermore, the meat firm used to sell its by-products and rest raw materials on the international markets, but when these markets experienced sharp decline and fluctuation, the firm had to seek other solutions. By contrast, the dairy firm used to sell whey as common whey proteins (whey concentrates) to its partner, although acknowledging the potential of whey hydrolysates as higher value-added products. This explained why the dairy firm did not feel an urgent need to find alternatives, but took the exploratory learning at its own pace.

4.2. Transformative learning and entrepreneurial experimentation

Newly acquired knowledge needs to be tested and turned into concrete actions via entrepreneurial experimentation. Entrepreneurial experimentation is the main source of reducing uncertainty, suggesting possible results from trials and failures. Entrepreneurs are not only new entrants but also incumbent firms who are diversifying their business strategy to take advantage of new developments, which is the case of the firms under study. Experimentation in the form of learning by doing and learning by using is vital for innovation to thrive (Carlsson and Stankiewicz, 1991; Dosi, 1988; Pisano, 1994). The transformative learning of ACAP enables firms to assimilate and transform valuable newly explored knowledge via experimentation, which allows them to develop knowledge 'tacitness' or “know-how”.

In early experimentation firms may be advantaged by being able to undertake interdivisional transfer of technical knowledge (Miller et al., 2007). This phase of ACAP is particularly important because the focus on R&D and knowledge acquisition may overlook the process needed to *assimilate and apply* the acquired knowledge (Lane et al., 2006). As a participant of the meat firm in the project III (see Table A4) confirmed:

> *Useful values are to take the knowledge that exists and the processes that have already been developed in other contexts, transfer them and adapt them to our raw materials.*

Through the research projects on PEH on a pilot/lab scale, the meat firm tested different types of enzymes on various rest raw materials and possible outcome products that respond to different market needs such as baby food, nutrition for the elderly and sports nutrition. These pilot research projects required a lot of testing and documenting to show that the end products produced good results. As one interviewee explained:

> *We have products from test or lab production, and we can show that this is what we are expecting to produce. We analyze […] and find out if the application has an effect in the body […] for example, metabolism. […] We [also need] to find add-on value in this product compared to other products in the market.*

The transformative learning process of the dairy firm, however, had already begun, in that it had started to look into the enzymatic hydrolysis a few years ago. Since whey was the most abundant rest raw material of the firm, it was natural that it started experimenting with this by-product in the first research project on the enzymatic hydrolysis (see project I in Table A5). This project was launched in 2017—thus it would take some time before the firm got any results.

The transformative learning of ACAP allowed the meat firm to experiment on the technology by testing different enzymes with different by-product types. Good results from the pilot projects provided the meat firm with a solid foundation for further developing the enzymatic hydrolysis of protein technology.

4.3. Exploitative learning and resource mobilization

The allocation of sufficient resources is indispensable to making knowledge exploitation possible. Resources are human, financial capital and complementary assets such as related services, products, and network infrastructure. Among them, financial commitment is one of the most important resources, acting as a necessary condition for innovative enterprises (Lazonick and Prencipe, 2005). Resources are an important input for knowledge development (about a specific technology) and for entrepreneurial experimentation to allow testing of new technologies in niche experiments. The exploitative learning phase emphasizes firms' ability to convert the assimilated knowledge into new products and services (Cohen and Levinthal, 1990). To do so, firms must mobilize necessary resources.

After the intensive transformative learning process about the enzymatic hydrolysis, the meat firm made an important decision: To invest in this technology to produce protein hydrolysates on an industrial scale—commercialization. Nevertheless, the mobilization of financial resources, especially the risk capital, was troublesome. As noted by an interviewee:

> *To develop and implement new innovative processes, technologies and applications take time, […] is risky and requires a lot of resources – it requires 'big muscles'. Even big firms such as ours have low margins and limited access to funding for taking the lead on innovations. […] More funding and access to risk capital will contribute to increasing innovation.*

Furthermore, raising funds for internal R&D projects was difficult as the department working on the by-product valorization had to compete with other departments in the same firm for funds. The decision to invest in the enzymatic hydrolysis plant was only made after the meat firm had received some public funding and successfully invited a partner to share the financial burden and reduce risks. The enzymatic hydrolysis project was a new joint venture between the meat firm and its partner, also a large firm selling feed ingredients in Norway. The plant was built in 2017 and expected to launch final products on the markets for human consumption in early 2020. In addition, the meat firm also invested in its human capital by hiring more people for the research team on the by-product valorization, as it recognized the great potential of this field.

As for the dairy firm, it was still at an early stage of investigating and learning more about the enzymatic hydrolysis. Thus, it decided:

> *We [the firm] follow what happens in other countries, what is published and communicated at seminars and conferences and so on. So, we follow the development of the field [the enzymatic*

hydrolysis of protein]. […] We wait and see. [If] the documentation is better, we should use it. (Interviewee statement)

“Wait and see” did not mean the dairy firm was static, however. It invested in human capital by increasing personnel in the by-product valorization department in order to be able to examine the potential of this technology and other potential technologies and possibilities for utilizing its rich by-product resources.

The exploitative learning of ACAP required the firms' dedication to turn the transformed external knowledge into commercial outputs by mobilizing necessary resources. Resources are needed in any phase of the ACAP process; however, they—and especially finance capital—are more decisive in the exploitative phase, as shown in the case of the meat firm. The findings of ACAP processes of learning—exploratory, transformative, and exploitative—of the dairy firm and meat firm are summarized in Table 3.

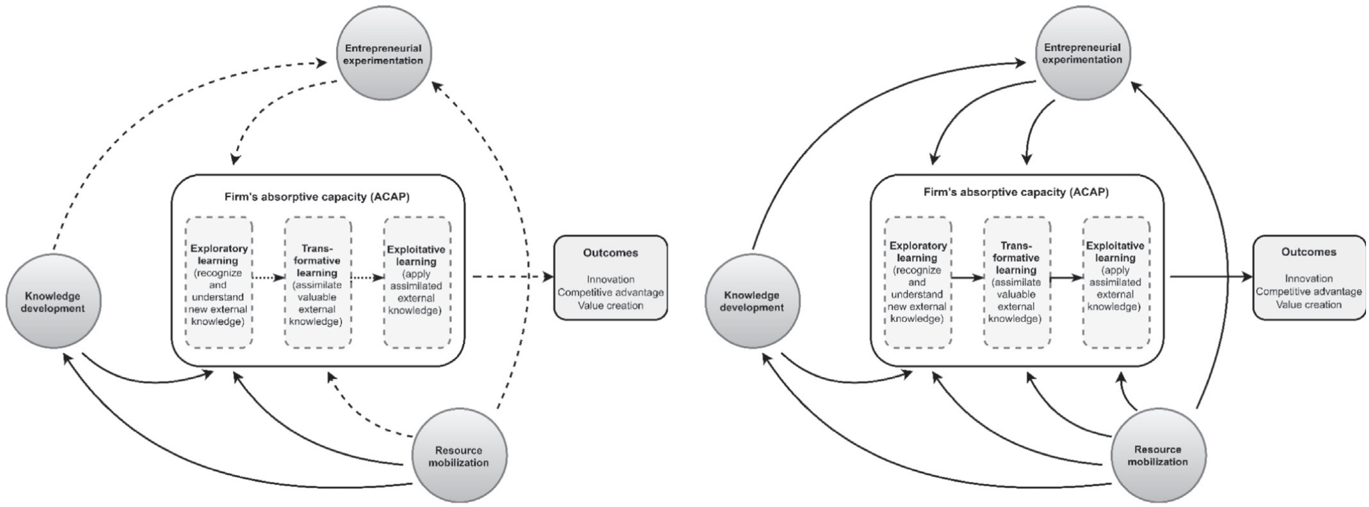
5. Discussion

Through the analysis of the ACAP processes, the study showed that the two firms—with similar organizational structure, cooperatively owned by farmers—had different policies with regard to the enzymatic hydrolysis of protein technology: They had dissimilar times of entry into the technology and reacted differently to the innovation opportunities. The meat firm was ahead and seemed to be more decisive and active in knowledge development (by acquiring necessary technical knowledge through a number of collaborative research projects via exploratory learning), in the entrepreneurial experimentation (by launching multiple pilot projects to transform the acquired knowledge via transformative learning), and in the resource mobilization (by mobilizing both financial and human capital to exploit the assimilated and transformed knowledge via exploitative learning). The dairy firm, by contrast, was still at an early stage of exploring the technology and investing in human capital to investigate its potential. The ACAP processes were activated and used differently by the respective incumbents.

Exploratory learning was decisive for the firms' knowledge development as it highlighted what knowledge (i.e. relevant and potential) had to be acquired and invested in. Since the by-product valorization was largely unrelated to the ongoing activities (i.e. the mainstream production and traditional markets), prior knowledge was insufficient for the incumbents to enter the new business area. In addition to the novelty of the technical knowledge, the protein ingredient market was absolutely new to them and they couldn't use the traditional market channels. To meet this challenge, they had to actively engage in knowledge search and experimentation as a basis for building in-house knowledge. Finance capital played a critical role in the ACAP processes, but most importantly in the

Table 3
ACAP process of learning of the dairy firm and meat firm.

Processing of learning—ACAP	Firm	Proportions	Representative quotes from the informants
Exploratory learning	Meat firm	Technical and general knowledge (knowledge content) via collaboration with research institutes and cross-industry, i.e. inter-industry learning	*“We have to develop knowledge and know what technologies to invest in, to seek knowledge outside at research institutes. […] We don't have a very large research department, so we are very dependent on the collaboration with research institutes.”* *“There is much expertise, knowledge in this project; not least it has done a lot of good work on fish, which I think we can translate in principle into the meat. Meat, as is known, is very good protein, completely at the height of fish protein.”*
		Market knowledge (baby food, elderly food and sports nutrition)	*“We [the firm] can offer a product that is unique and stands out from alternatives, which fulfills a need and has a long-term competitive advantage.”*
	Dairy firm	Knowledge content, general knowledge base	*“Working with external research institutes/research partners is a very important strategy for us as [the firm] has a need to develop and expand its knowledge base. We cannot do everything on our own as we do not have competences in all fields. By using research projects, we can access and develop knowledge and insights from our cooperative network.”*
		Market knowledge	*“We will not do anything if we don't see a market for it.”*
Transformative learning	Meat firm	Assimilating the knowledge	*“Useful values are to take the knowledge that exists and the processes that have already been developed in other contexts, transfer them and adapt them to our raw materials.”*
		Experimentation with entrepreneurial mindset Knowledge ‘tacitness’ or “know-how”	*“We have products from test or lab production, and we can show that this is what we are expecting to produce. We analyze […] and find out if the application has an effect in the body […] for example, metabolism. […] We [also need] to find add-on value on this product compared to other products in the market.”*
	Dairy firm	More research needed	*“We have been involved in a couple of projects with research institutes, but we have not invested much. […] More research is probably needed to prove that hydrolysates are better than whey proteins in sports products.”*
Exploitative learning	Meat firm	Risk investment Financial resources mobilized	*“To develop and implement new innovative processes, technologies and applications take time, […] is risky and requires a lot of resources – it requires “big muscles”. Even big firms such as ours have low margins and limited access to funding for taking the lead on innovations. […] More funding and access to risk capital will contribute to increasing innovation.”*
	Dairy firm	Strategy: “Wait and see” for a mature opportunity	*“We [the firm] follow what happens in other countries, what is published and communicated at seminars and conferences and so on. So, we follow the development of the field [the enzymatic hydrolysis of protein]. […] We wait and see. [If] the documentation is better, we should use it.”*



The case of the dairy firm The case of the meat firm

Fig. 3. The scheme of analysis of the two case studies—author's illustration based on Cohen and Levinthal (1990) and Lane et al. (2006).

exploitative learning phase. The findings summarized in Table 3 are illustrated in Fig. 3.

Our understanding of how ACAP exerts its influence on innovation and competitive advantage, and is subsequently transformed in an organizational context, is limited (Volberda et al., 2010; Watts and Hamilton, 2013). This study provides empirical evidence for this role. The outcome for the meat firm was product innovation, i.e. protein hydrolysates in various forms. The meat firm expected to launch the products on the market next year. This link is represented by the continuous arrows in Fig. 3. However, as the dairy firm was still in an early process of searching and investigating the technology, the direct output and innovation outcome—represented by the discontinuous arrows in Fig. 3—was not yet visible. This paper sets out the importance of developing the absorptive capacity for innovation, value creation, and competitive advantage.

The study notes the importance of intra-organizational aspects through the analysis of ACAP in relation to the incumbents' knowledge development, entrepreneurial experimentation, and resource mobilization. It underlines firms' ability to acquire external knowledge and transform it into innovations by mobilizing necessary resources. Roy and Sarkar (2016) posit that technological knowledge is likely to be more beneficial than market knowledge for responding to radical technological changes. However, this study finds that both sources of knowledge are equally important. The meat firm searched for both types of knowledge at the same time. It would not embrace the PEH technology without understanding market needs. The study supports the findings of Hansen and Coenen (2017) that learning about new markets for new bio-products is vital, but not enough to ensure resource mobilization. To unlock investment capital, firms must secure demand. By establishing a joint venture, the meat firm was assured of supplying protein feed ingredients to its partner.

Intra- and inter-organizational aspects cannot be separated (Volberda et al., 2010). This study shows such a close link. It notes the significance of utilizing research collaboration (Goes and Park, 1997; Steensma and Corley, 2000), especially in the process of knowledge development and entrepreneurial experimentation, which both firms acknowledged. Research collaboration is particularly important in the context of the bioeconomy in which the new knowledge is complex and evolves rapidly, making it more difficult for incumbents to capture and capitalize on all relevant knowledge domains (Lane et al., 2006). The study confirms the importance of interdisciplinary collaborations and collaborations between academics and firms in knowledge and technology transfer in the bioeconomy as discussed by Borge and Bröring (2017, 2018). Further, the study stresses the pertinence of inter-industry learning—in this case, the knowledge transferred from the Norwegian fish industry was valuable for the meat and the dairy industry, which is an important domain for cross-industry innovation as indicated by Ciliberti et al. (2016). This signifies that similar culture and cognitive structures enhance the knowledge absorption of ACAP.

This paper discusses the role of the absorptive capacity for incumbent firms in general and the food industry in particular, especially the meat and dairy sectors, in the transition toward more sustainable food processing. Since by-product valorization is a new and unfamiliar field, food firms may encounter multiple challenges in developing their ACAP and innovations such as difficulty in comprehending of new knowledge domains, high-risk investment or uncertainty of new markets and demand. Thus, in order to generate new technological innovations and create value for by-product resources, firms should put forth more effort in developing absorptive capacity through delicate organizational learning. They should not only rely on their own knowledge base and resources, but also look for external knowledge and competences that are relevant, testing new knowledge in house by doing pilots projects as well as investigating thoroughly potential markets and demand before they start investing in production. They should also be aware that new knowledge does not only come from universities or research institutes but also from other industries with a similar culture and cognitive structure. Different needs can emerge in the different phases of the learning process; it is important that firms take them into account to mobilize pertinent resources accordingly.

6. Conclusion

The bioeconomy entails utilizing all bio-based resources, which requires the full commitment of key actors throughout the economy in order to transform our world to a more sustainable development (United Nations, 2015). In this sense, this study points to the active engagement of Norwegian food processing firms in valorizing their by-product resources. The paper makes a couple of contributions:

As regards transition studies, the paper contributes to the under-studied topic of the role of incumbents in transition processes, especially firms in low-tech industries. Despite the fact that firms and organizations are assigned a key role in the adoption, development, and diffusion of innovations, transition research has made little effort to investigate how 'actors'—incumbent firms—explore and exploit technological opportunities. By studying the ACAP processes, this paper shows how the incumbent firms explore new knowledge domains for by-product valorization, and how this helps to move forward the development of this particular technology and innovation dynamics during the transition toward the bioeconomy. Knowledge development, entrepreneurial experimentation, and resource mobilization go hand in hand with the incumbents' learning process.

In respect of the management literature, the study reinforces the importance of developing absorptive capacity at the organizational level as it affects the outcome of innovation and competitive advantage especially in a new business environment. Given the context of the developing bioeconomy, absorptive capacity is even more crucial for firms if they wish to create added value for their by-product resources. The study notes the significance of firms' investment in absorptive capacity and presents evidence that the investment is responsive to the innovation outcome. Additionally, the paper throws light on the link between intra- and inter-organizational aspects in a non-R&D context, whereby a firm, by using its ACAP, interacts with its network to develop the necessary knowledge base through research collaboration with research institutes and proximate industries. Based on the analysis of the two case studies, this paper provides an example of how incumbent firms instigate their absorptive capacity to develop innovations for food by-product valorization, which could be learned by other meat and dairy firms worldwide.

A major motivation of technological innovation studies is to inform policymaking (Markard and Truffer, 2008). Through an actor-oriented analysis of the incumbent firms in the Norwegian food industry, there are several issues this paper draws to the attention of policymakers. Despite the environmental and economic potential of organic by-product valorization, it is a new business area where—in contrast to mainstream production—the incumbents have little prior knowledge, resulting in a hesitancy to invest. In addition, costly investment in new technologies and machinery, as well as challenges in building new knowledge bases, can be barriers. Most importantly, the lack of funding creates a chasm between research and industrial development. Additionally, the meat firm faced the challenge of finding a technology vendor who could provide the necessary equipment and machinery on an industrial scale. In contrast to well-established business processes, the infrastructures and networks for by-product valorization have not yet developed. This causes more problems for firms to develop innovations. To increase the success rate of industrial innovations, policymakers should seek to bridge this gap. Lastly, since the valorization was a new field, the firms needed regulative and legislative guidance, especially about animal by-products. To enter a new market, the firms had to prepare numerous documents to gain approval. Since there are strict regulations concerning animal by-products, regarding what is allowed and what is not, the meat firm needed (and needs) clear directions in the guidance, e.g. how the by-products can be used in new applications. However, it takes time to develop legislation, which can slow down the business development process. By responding to the firms' needs, i.e. providing good and timely support and sufficient policies, the regulator can help firms cope with such challenges and might speed up the transition process. In short, this study highlights three aspects of the situation of incumbent firms in the transition toward a sustainable bioeconomy that policymakers need to address: (i) Support public funding to reduce the gap between R&D and commercialization, (ii) create a common platform and network to connect actors, and (iii) provide timely new policies, new supportive guidance and regulations. These issues are particularly important in the early phase of the transition process, given that the bioeconomy is still developing and that by-product valorization is a new business area to most firms. If these limitations are not mitigated in a timely fashion, they might hamper the development of technological innovations for sustainability transitions.

Since this study focuses on the managerial aspects of by-product valorization in food processing firms, it could not provide a full picture of how an entire value chain of this particular technology, i.e. enzymatic hydrolysis of protein, looks like. Future research can reveal how the adoption of technology implies networking and system changes, and how different actors involved along the value chain engage in cross-industry innovations.

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Declaration of competing interest

No conflict of interest exists.

CRediT authorship contribution statement

Nhat Strøm-Andersen: Conceptualization, Data curation, Formal analysis, Writing - review & editing.

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Appendix

Table A1
List of interviews

	Date	Organization	Position	Duration	Type of interview
1	February 12, 2016	Meat firm	Business Development Manager	2.5 h	Personal interview
2	February 16, 2016	Dairy firm*	Research Director Head of Corporate Social Responsibility Technical Director	2 h	Phone interview
3	April 20, 2016	Rendering industry	Product and Sales Manager	1.5 h	Phone interview
4	May 13, 2016	Meat firm	Business Development Manager	1 h	Personal interview
5	April 20, 2016	Meat firm	Purchasing Manager	1.5 h	Personal interview
6	July 11, 2016	Research institute	Researcher	1.5 h	Personal interview
7	June 16, 2017	Meat firm	Business Development Manager	2 h	Personal interview
8	September 22, 2017	Meat industry	Chief Executive Officer	10 min	Phone interview
9	September 26, 2017	Dairy firm	Research Director	1 h	Phone interview
10	March 15, 2018	Industry Confederation	Managing Director	1 h	Personal interview
11	March 19, 2018	Government Agency	Senior advisor	30 min	Phone interview
12	June 27, 2018	Dairy firm	Sustainability Manager	30 min	Phone interview
13	June 28, 2018	Meat firm	Process and Analysis Manager	67 min	Personal interview
14	December 18, 2018	Meat firm	Process and Analysis Manager	66 min	Personal interview
15	May 09, 2019	Meat firm	Business Development Manager	50 min	Personal interview
16	May 09, 2019	Meat firm	Senior Scientist	50 min	Personal interview
17	June 19, 2019	Norwegian Meat and Poultry Association	Director	1.5 h	Personal interview

* This interview was done with three informants.

Table A2
Interview guide for the first round of interview based on a value chain perspective[81]

Stages of value chain	Questions
Resource	● What are the firm's main strategies concerning organic residues, by-products, residues/wastes? ● What types of organic residues, wastes, by-products are generated at the firm? (Waste categories and the volume)? ● What are traditional uses for those wastes, residues/by-products, and what are the most promising valorization pathways?
Collection/Transport and storage	● How do you collect/gather the wastes, residues? ● What are the challenges concerning collecting and transporting them? ● Do you evaluate any new technologies/processes for reducing the environmental impact of transportation? ● What are the main technologies needed to carry out these activities? (Who are your technology providers?) ● Does the firm have any key partners in this stage?
Processing/Technology	● How are these residues processed? ● What are technologies needed to carry out main activities/processes? Different technologies needed at different stages of the process/ value chain? ● What is the energy and environmental performance of these technologies? ● Who are your technology providers? And the costs? ● What types of partners does the firm collaborate with in this stage?
End Product(s)	● What are outcome products derived from the wastes, residues? ● Who are end-users of these products? ● Before launching/developing new products derived from the waste valorization, do you test the consumer readiness? ● Are you collaborating with partners in this sense? ● What are the most important incentives and demand factors for the new products (derived from organic residues)? ● What are the most important barriers for developing new products based on organic residues at the firm? ● Besides the current production portfolio, does the firm consider develop new products out of the organic residues with higher value?
Market(s)	● What are the markets the firm aimed at? And why those markets? What is the firm's market share in those markets? ● Any particular suppliers you are working with? ● Do you meet any competition in those markets? ● Do you have problems in assuring the demand for final products derived from waste valorization? ● Who are the key firms (lead firms) in those markets?
Distribution	● Do you rely on a distribution network? Who are your main partners? ● What is trade volume of the product? ● What are contract terms with the distributors?
Policy frameworks	● What are the existing rules/regulations concerning valorization of organic residues in Norway and/or Europe? ● Which policies (subsidies, taxes, standards, regulations, RD&D activities etc.) and other national government or NGO initiatives are important for investment decisions and development of new products? (The role of policy and regulation in developing new products based on organic residues)? ● Is the firm willing to engage in (or influence) policymaking processes?
Environmental impacts	● Has the firm performed any environmental impact analyses (LCA) of the use of organic residues? ● Or for investigating the environmental performance of your processes for residues? ● What was the reason for initiating environmental assessments or not?
Other question(s)	● What are incentives and disincentives for the value creation of by-production valorization in different chains/production segments?
End of interview	● Could you suggest some relevant firms or individuals who you think we should interview also?

Table A3
Interview guide for the second round and/or follow-up interview based on the learning process of the firm(s)

Process of learning	Questions
Exploratory	● Why are you [the firm] particularly interested in this technology (i.e. the enzymatic hydrolysis of protein)? ● When do you start looking/exploring at potential new markets and technologies for by-product valorization (rather than just selling them on rest raw material markets)? ● What are the most important markets for the end products that result from this technology? ● What types of knowledge do you need? And why? ● What types of external knowledge do you seek? And why? ● Where do you seek the needed knowledge? ● What types of innovation are you going to develop?
Transformative	● How do you apply the acquired knowledge? ● Can you describe the process? ● What types of partners do you collaborate with?
Exploitative	● What types of resources do you need to carry out the project? ● What do you need to do to commercialize the innovation? ● Do you consider by-product valorization as long-term strategy? If so, how are you going to exercise this strategy? Let's say, for example, which areas will you focus on and what are you going to do in 5 years' time?
Other question(s)	● How do you perceive the industry's environment? ● What do you think about the importance of learning and updating new knowledge and technologies?

Table A4
Overview of the meat firm's research projects on the enzymatic hydrolysis of protein technology[91]

Project number	Time frame	The firm's role in the project	Type of by-products, residues	Current solution(s) and/or market(s)	Knowledge base, Research path(s)	Potential outcome(s)/product(s)/market(s)
I	**2012–2015**	Partner	By-products derived from animal (e.g. chicken bone) and marine industries	Low value products markets	Increase the knowledge of enzymatic hydrolysis of residues from animal and marine industries through the development of rapid screening techniques for controlling and monitoring of processes. Stable quality protein hydrolysates require good control over the raw material variation	Potential markets for industrial utilization of protein hydrolysates. Reduced production wastes and increased sales value of by-products.
II	**2012–2018**	Partner	By-products from meat and marine production and other Norwegian biomass	NA	Develop competitive enzyme technology and identify the promising enzymes better suited for industrial use, such as enzymes using bioinformatics, protein engineering and gene shuffling-based directed evolution. Develop high-value hydrolysates from protein-rich by-products through enzymatic conversion technology. Screen and characterization of candidate enzymes, enzyme engineering and larger-scale production for industrial trials.	Increased value creation in Norwegian bio-based industries. A good bio-economy based on sustainable, environmental-friendly and profitable processes. Considerable synergies of the blue and green sector.
III	**2013–2017**	Partner	Rest raw materials from fish, chicken and vegetables	NA	Develop novel sensor and automation technology, bioprocessing technology. Convert raw meat materials using enzymes to prepare protein powder and oil	Novel automated quality differentiation and sorting concepts that increase resource utilization of food loss and reduce wastes. Ingredient in various foodstuffs.
IV	**2013–2017**	*Coordinator*	Chicken by-products (e.g. chicken bone)	Meat meal production and low-value feed applications	Explore the potential of chicken bones as the base raw material to produce liquid or dried peptide hydrolysate with high quality and high value application. Identify, characterize and quantitate processed peptides through the process of enzymatic breakdown of protein.	Novel food and feed ingredients as peptides with bioactive properties with potential obesity-reducing effects.
V	**2014–2017**	Partner	Low value side-streams, e.g. potato peel starch, chicken feather	NA	Develop a liquid biodegradable mulch film to control weeds in row crop production by using potato starch and hydrolyzed chicken feather	Environmental-friendly substitute for herbicides, as well as for petroleum-based polymer mulch films. Enhanced knowledge and competence in development and characterization of films.
VI	**2015–2023**	Partner	Biomass unsuitable for direct human consumption, e.g. wood, seaweed and by-products from slaughterhouses	NA	Develop protocols for converting biomass to hydrolysates for use in yeast production by applying enzyme technology. Innovative feed processing technology, conversion of national bioresources into feed for farm animals and fish	Production of novel feed ingredients for farm animals and fish. Contribution to the growth and value creation of the Norwegian aquaculture and agriculture industries.
VII	**2017–2019**	*Coordinator*	12 000 tons of chicken by-products from mechanical deboning process	Low value feed ingredients	Convert low-value plus products into high-value ingredients and foods for higher-paying markets by using enzymatic hydrolysis of protein	Protein hydrolysates for the sport/fitness market, and the elderly market. Development of new ingredients for

Table A4 (*continued*)

Project number	Time frame	The firm's role in the project	Type of by-products, residues	Current solution(s) and/or market(s)	Knowledge base, Research path(s)	Potential outcome(s)/product(s)/market(s)
						functional food and innovative food products for consumers
VIII	**2017−2020**	Partner	Chicken carcasses from poultry and whey from dairy processing	NA	Use Fourier-transform infrared (FTIR) spectroscopy-based rapid screening with ligand fishing technologies for facilitated discovery of antidiabetic peptides in protein hydrolysates. Screen and identify bioactive principles in protein hydrolysates	Efficient and high quality screening program for bioactive constituents in complex food product

Table A5
Overview of the dairy firm's research projects on the enzymatic hydrolysis of protein technology[10][1]

Project number	Time frame	The firm's role in the project	Type of by-products, residues	Current solution(s) and/or market(s)	Knowledge base, Research path(s)	Potential outcome(s)/product(s)/market(s)
I	**2017−2020**	Partner	Chicken carcasses from poultry and whey from dairy processing	NA	Use Fourier-transform infrared (FTIR) spectroscopy-based rapid screening with ligand fishing technologies for facilitated discovery of antidiabetic peptides in protein hydrolysates. Screen and identify bioactive principles in protein hydrolysates	Efficient and high quality screening program for bioactive constituents in complex food product

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