Towards the Circular Economy in the Swedish Biobased Industry:

Leveraging the Value of Digitalization and Artificial Intelligence

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Programmet finansieras av Vinnova, Energimyndigheten och Formas samt de intressenter från näringsliv, akademi, institut och offentlig sektor som deltar. Målet är att öka förädlingsvärdet och konkurrenskraften i den svenska biobaserade sektorn genom att skapa bästa möjliga förutsättningar för att ta fram nya biobaserade material, produkter och tjänster.

Vision: Sverige har ställt om till en bioekonomi 2050.

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Abstract

Making the transition to a circular economy is an important goal for society as a whole and for individual companies, particularly in resource-intensive industries. Digitization and Artificial Intelligence (AI) has been identified as key enablers for firms in successfully making such a transition. However, the complexities involved in such an undertaking mean that very few individual firms can achieve it alone and that ecosystem-wide orchestration of resources is necessary. Based on a qualitative study of four value chains in the Swedish biobased industry we develop a process model that describes the scarcely understood process of digital transformation toward a circular economy paradigm. First, we provide evidence that firms in the biobased industry achieve the digital transformation towards a circular economy by engaging in the transformation in four stages: 1) transformation in *technologies*; transformation in *activities*; transformation in *boundaries*; and transformation in *goals*. For each stage, specific key mechanisms are identified. Second, we outline a number of collaborative arrangements for leveraging the value of digitization and artificial intelligence in the biobased industry, including collaboration with other SIPs and academia. Third, we identify recommendations for a thematic call from BioInnovation.

Introduction

The goal of the circular economy paradigm is to minimize waste through cycles of reduction, reuse, and recycling with limited leakage and minor environmental impact (Ellen MacArthur Foundation, 2016; Pearce & Turner, 1990). While the circular economy debate is concerned mainly with societal actions and benefits, more attention is needed to establish how the circular economy paradigm can be implemented at the firm and ecosystem levels (Frishammar & Parida, 2018).

Digitalization is increasingly viewed as a key enabler and driver of value creation and value capture for today's firms (Holmström, 2018; Nylen & Holmström, 2019). As smart digital technologies entail the combination of products, services, software, and analytics (Porter & Heppelmann, 2014) many firms are moving towards optimization, control, and, ultimately, autonomous systems with advanced functionalities based on digital technologies and AI.

While many firms are struggling with overcoming the challenges associated with data collection, warehousing, analytics, and prediction, leading companies such as ABB, LKAB and Volvo are rapidly moving toward creating value from digitization and AI (Svahn et al., 2017; Jonsson et al., 2018; Parida et al., 2019; Westergren et al., 2019; Sandberg et al., 2020). As these successful examples of leveraging value from digitization and AI demonstrate, increased and mindful use of digitalization and AI may enable not only improved preventive and proactive maintenance of key processes, but also more effective and efficient value creation and capture. But these examples also demonstrate that increased use of digitalization and AI also adds complexity and creates challenges for the involved firms.

It is critical that firms in the biobased economy are aware not only of the opportunities associated with increased digitization, but also of the associated challenges. The idea of the bio-economy represents a political and industrial initiative to ensure that our society can rely on renewable biological sources while achieving economic growth. The concept of a bio-economy—also called the biobased economy or knowledge-based bio-economy—can be understood as an economy where the basic building blocks for materials, chemicals and energy are derived from renewable biological resources, such as plant and animal sources (European Commission, 2012).

However, while the literature on the bio-economy often discusses the importance of digital technologies and their role in a successful shift to a bio-economy, much of the discussion that is related to the enabling role of digital technologies is fragmented and immature. Even though digitization in general, and AI in particular, have been identified as key enablers for digital transformation and the transition towards a circular economy, the complexities involved in such an undertaking are not well understood (Frishammar & Parida 2018; Parida et al., 2019). It has been argued that in order to succeed with the transition to a bio-economy, there is a need to focus more on the organizational and economic feasibility of such initiatives because technological innovations alone are insufficient without an understanding of the social dynamics involved (Chesbrough & Rosenbloom, 2002). While insightful, it remains unclear how a firm can use this insight to succeed with the digital transformation challenges they are faced with.

Based on a qualitative study of four value chains in the Swedish biobased industry we develop a process model that describes the scarcely understood process of digital transformation toward a circular economy paradigm. Specifically, our research question is: *What are the challenges and opportunities associated with leveraging the value of digitization and AI in the Swedish biobased industry?*

The remainder of the report is as follows: We begin by presenting insights from the literature, specifically the key challenges and opportunities associated with digitization and AI, with a particular emphasis on the enabling role of digitization and AI and the dynamics of digital transformation. After presenting the research method behind the report we present evidence from the case study of how firms from four sub-dimensions to the biobased value chain are working towards the circular economy ideal and how digitalization is enabling them to work towards that ideal. By so doing we pay specific attention to the opportunities and challenges arising in such digital transformation processes for each sub-value chain. In the discussion section we articulate 1). a maturity model outlining how firms in the biobased industry should address the digital transformation challenge; 2). Collaborative arrangements for leveraging the value of digitization and artificial intelligence in the biobased industry, and 3). recommendations for a thematic call from BioInnovation Sweden.

Transforming value chains into value cycles

The bio-economy is defined as the production of renewable biological resources and the conversion of these resources and waste streams into value-added products, such as food, bio-based products, and bioenergy. This definition covers both traditional (e.g., agriculture, forestry, food, and pulp and paper production) and emerging sectors, as well as parts of the chemical, biotechnological, and energy industries (see e.g. Scarlat et al., 2015). This approach is highly aligned with the circular economy idea, which refers to a model of production and consumption that is fundamentally different from the "linear economy" model that has dominated society since the emergence of the industrial age. The linear economy is based on a simple, linear process – extract, produce, consume and trash – with little or no attention to the spill and pollution generated at each step. In contrast, the linear economy model is characterized by the consideration it gives to economic objectives, with little regard for ecological and social concerns.

This development is aligned with the established definition of the circular economy by the Ellen MacArthur Foundation:

Looking beyond the current 'take-make-waste' extractive industrial model, the circular economy is restorative and regenerative by design. Relying on system-wide innovation, it aims to redefine products and services to design waste out, while minimizing negative impacts. Underpinned by a transition to renewable energy sources, the circular model builds economic, natural and social capital. (Ellen MacArthur Foundation)

A bio-based value cycle is – ideally – circular in the sense that the production and refinement of raw material is followed by consumption and then a recycling/reintroduction phase, which makes the waste minimal and the process highly circular.

Figure 1. The traditional value chain

The traditional value chain (see figure 1) is defined as a collection of activities to create value for customers to gain competitive advantage and ultimately gain economic success (Porter, 1985). In contrast, the goals of the circular business model and sustainable business model are creating sustainable value, pro-active multiple stakeholder management, and long-term perspective. To gain organizational sustainability, and practicing circularity in the value chain is essential which creates competitive advantage, reduces import of raw materials and meets customer demand in an economical and sustainable way.

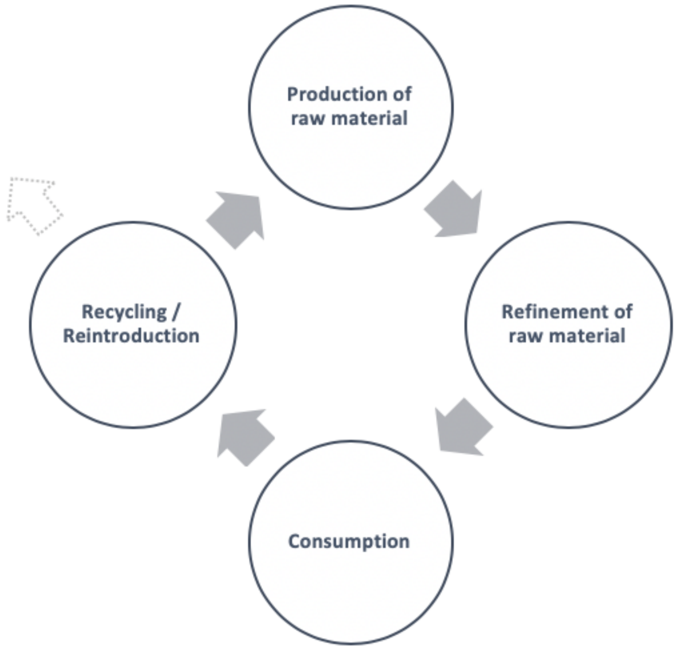

Figure 2. The value cycle

The transformation of value chains into value cycles is associated with the complex challenges that individual firms and society as a whole is faced with. For the bio-based industries in particular, The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning identifies a number of challenges that emerge throughout the value cycle (see figure 3), including the realization of more sustainable use of material and resources, change in consumer behaviors, and the closing of linear resource flows through recycling or reintroducing (Formas, 2012).

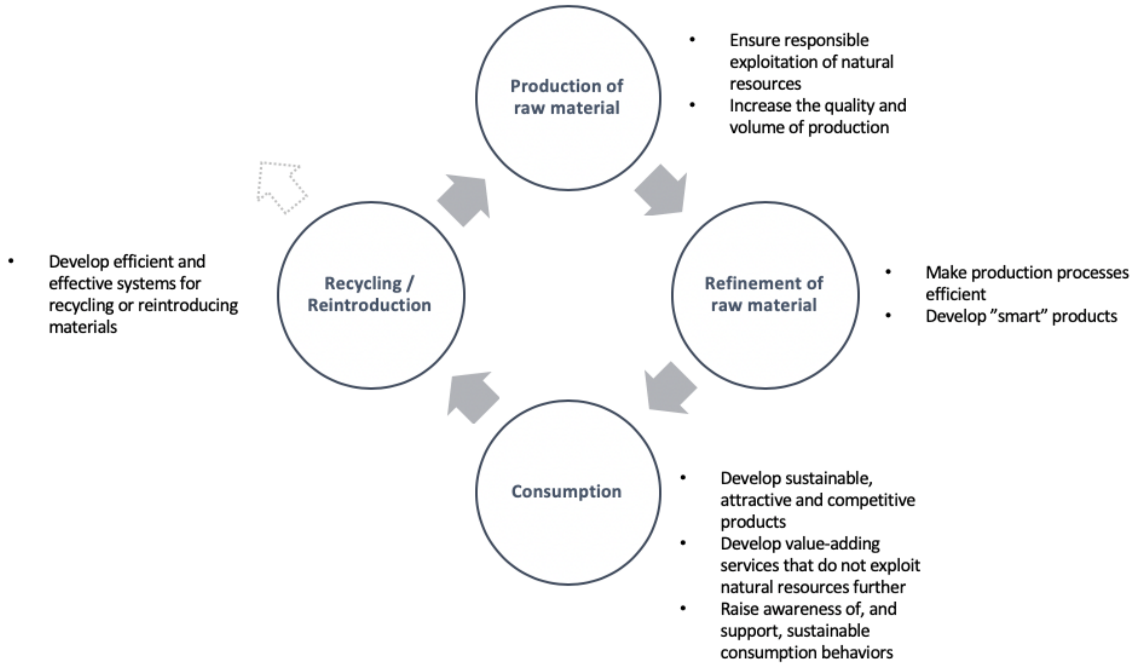

Figure 3. Known challenges with transforming value chains to value cycles (adapted from Formas, 2012).

While overwhelming, these challenges can be addressed, and digitization and AI hold the potential to serve as tools for addressing them.

Digitization and Artificial Intelligence: Challenges and Opportunities

The enabling role of digitization and AI

The circular economy entails the creation of a restorative, re-generative industrial system (see Ghisellini et al., 2016). As such, the circular economy logic of make-remake-use-return challenges the linear economy logic of take-make-use-dispose. In this context, the enabling role of digital technology is critical. In recent years, a particular interest has been targeting AI technologies. AI technologies are now being used within a variety of organizational practices, creating new types of human-machine configurations and playing an increasing role in the context of contemporary organizing (Boden, 2016; Seidel et al. 2018). Examples can be found across areas such as management decision making, manufacturing, and design (Kittur et al. 2019). The interest in digitization in general, and AI in particular, is seemingly only accelerating.

AI technologies are now experiencing a surge in diffusion, as AI has gained momentum as a potentially disruptive set of technologies in many industry areas, such as financial, automotive, retail, travel, and media (Chui, 2017). In recent research, AI has been defined according to two core abilities 1) as the ability of machines to carry out tasks by displaying intelligent, human-like behavior; and 2) as the ability of machines to behave rationally (i.e., as intelligent agents) by perceiving the environment and taking actions to achieve goals (Russell & Norvig, 2016).

While AI seems to be peaking in research as well as in practice at the moment, the development of AI research has been characterized by ups and downs. A first wave of general enthusiasm in the late 1950s was linked to the ability to build programs capable of proving mathematical theorems, or playing simple games (Russell & Norvig, 2016). Such initial enthusiasm was followed by a period of disillusion, where promises of AI systems being able to display levels of intelligence similar to, or even higher than, humans were met with repeated failures. This was partly due to the immaturity of computing technology at the time, but along with the rapid increase in computing power, many authors refer to AI as bringing in a new revolution, as a consequence of how machines have transformed the way work is carried out by humans (e.g. Makridakis, 2017).

Despite increasing enthusiasm, however, most researchers agree that what we are witnessing today is the diffusion of weak AI technologies, as opposed to strong AI. *Strong AI* refers to hypothetical systems with human or superhuman intelligence, that simulate the complex human ability to think and to execute intelligent tasks such as ethical judgments, symbolic reasoning, managing social situations, and ideation (Brynjolfsson & McAfee, 2014). On the other hand, *Weak AI* refers to systems capable of carrying out tasks that require single human capabilities, e.g., visual perception, understanding context, probabilistic reasoning, and dealing with complexity (Russell & Norvig, 2016). Only the weak form of AI is of interest for real-world applications, as strong AI systems are still considered an area of speculation and science fiction (for a discussion, see Tegmark, 2017).

Digital technologies are radically changing the way firms operate (Henfridsson and Bygstad, 2013; Jonsson et al., 2018) and it is hard to deal with organizing without considering digital technology (Kallinikos et al., 2013). Simply put, digital technologies are integral to contemporary firms to the extent that organizing and digitization are two sides of the same coin. Digital technologies are seen as ''products or services that are either embodied in information and communication technologies or enabled by them'' (Lyytinen et al., 2016, p. 49). As such, they exist in the shape of digital tools (e.g., Aldrich, 2014), digital platforms (e.g., Tiwana et al., 2010), or artifacts with digitized components (e.g., Ekbia, 2009). While there is a broad range of digital technology types, a common theme for all types of digital technology is the decoupling of digital information from the physical form of the material device (Yoo et al., 2010).

In order to enable a high level of precision in the analysis, some core definitions need to be made. It is unfortunate that terms like digitization, digitalization and digital transformation are used in a sweeping way as they refer to fundamentally different things:

Term	**Definition**	**Key references**
Digitization	A technical process transforming analogue formats into digital formats	Tilson et al 2012; Sandberg et al 2020

Digitalization	A sociotechnical process of applying digitizing techniques to broader social and institutional contexts that render digital technologies infrastructural	Yoo et al 2010; Nylen and Holmström, 2015
Digital Transformation	Digital transformation is the profound transformation of organizational activities, boundaries and goals to leverage the opportunities of digital technologies	Matt et al. 2015; Vial 2019

Table 1: Key digital terminology

It must be clear that digitalization cannot occur without digitization. Digitization is the conversion of analog to digital, whereas digitalization is the use of digital technologies and digitized data to impact how work gets done, how customers and firms engage and interact, and how revenue streams are created. Digitization refers to the internal optimization of processes (e.g., work automation) which often results in cost reductions. Conversely, digitalization is process that goes beyond the implementation of technology to imply a deeper change to the entire business model and the evolution of work. In the end, very few businesses have undergone successful digital transformations. For instance, Kane et al (2017) found in a global study that only 25% of organizations had transformed into digital businesses, 41% were on transformative journeys, and 34% invested more time talking about the digital transformation trend than they did acting on it. What is noteworthy form this study, however, is that 85% of executives stated that attaining digital maturity is critical to organizational success.

Because they embody digital capabilities, digital technologies are typically malleable, editable, self-referential, and interactive (Garud et al., 2008; Kallinikos et al., 2013; Nambisan et al., 2017), which allows them to evolve continuously even after implementation and use and to generate new forms of agency. To describe digital technologies and explain how they act as enablers of organizational activity, we draw on the analytical construct of 'mechanisms.' Mechanisms describe the processes that underlie relationships between causes and effects (Gross, 2009), and mechanism-based theorizing is particularly appropriate for process-oriented, phenomenon-driven, field-level research (e.g., Henfridsson & Bygstad, 2013) which applies to the case of digitization in the biobased industry.

Digital transformation dynamics

Digital transformation has been referred to as "a *process* that aims to improve an entity by triggering significant changes to its properties through combinations of information, computing, communication, and connectivity technologies" (Vial 2019, p. 118), and also as a *journey* without specific end (Kane 2017). Investing in the continuous undertaking of digitally transforming one's firm implies articulating and enacting digital innovation and transformation strategies aimed to compete more effectively in a digital economy (Matt et al. 2015). Such efforts involve a highly dynamic process of iterating between learning and doing (Chanias et al. 2019).

Research on digital transformation focuses on mechanisms and processes through which the expansive power of digital technology is harnessed to transform firms' activities, boundaries, and goals (Aldrich and Ruef 2006; Matt et al. 2015; Vial 2019).

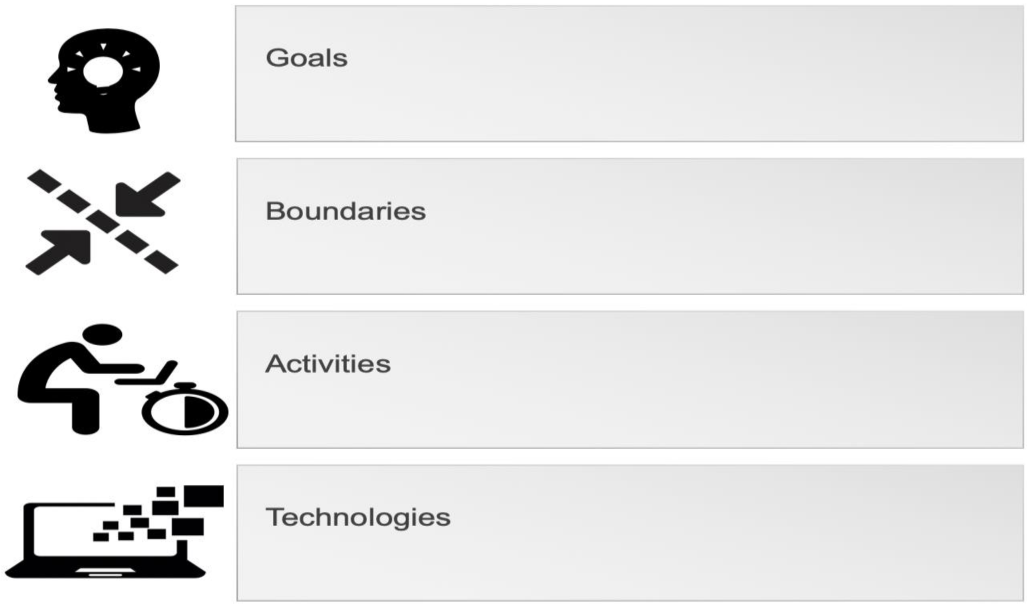

Figure 4: Digital transformation dimensions

These dimensions in the digital transformations serve as a scaffolding process in which technologies serve as the first step. This is followed by transformation in dimensions such as activities (i.e. what organizational members and the organization as a whole do), transformation in boundaries (i.e. changes in relations between the focal organization and its environment) and finally transformation in relation to an organization's goals.

Research method

The research presented in this paper adopts an interpretive case study approach (Lee, 1989) to develop an explanatory, mid-range theory of digital transformation in organizations. The goal is to provide an altered understanding of how things are or why they are as they are (c.f. Gregor, 2006). Such explanatory findings may inform normative theories in the future. To this effect, the study was designed to cover a broad scope based on the collection of empirical data to enable an inductive understanding of the digital transformation process in the context of the biobased industry.

Data validity is a problem for any study, not only because of the interpretive nature of the data, but also because of the intersubjectivity of data capture. By necessity, the research subjects are not only observed, but actively influenced by the researcher. To address this threat to validity, 11 semi-structured interviews with key informants are used as the key source of evidence. The interviews were conducted supported by an interview guide containing open-ended questions. The informants include respondents from four sub-dimensions of the biobased value chain: Packaging, wood construction, chemistry, and textiles and fashion. All interviews were recorded and transcribed (Yin, 1994). For further triangulation, internal documents from the firms, such as presentations and product documentation, were used as further evidence (c.f. Yin, 1994).

We coded the data in two broad phases: The first phase aimed to capture the event time series of the digital transformation process. Coding categories were generic process codes (Van de Ven and Poole, 1995), and to determine concepts and their properties, we applied an open coding procedure. The authors jointly coded the data, identifying initial concepts and higher-level categories using a constant comparative method and resolving any disagreements through discussion (Saldana, 2009). The outcome of this coding phase was an event outlining the unfolding of digital transformation with an unstructured list of concepts that seemed to be relevant in the process.

The initial findings triggered a second phase of coding as well as additional data collection targeted at the emergent concepts of importance. In this second phase, we turned to the relevant literatures for focal categories of coding. These categories – building on the notions of technologies, activities, boundaries and goals as key dimensions in the digital transformation process – allowed us to systematically relate the various concepts produced in the open coding phase. The emerging themes spurred a new literature search for theoretical arguments, explaining the findings in relation to the digital transformation literature.

Digitization and Artificial Intelligence in the Biobased Value Chain

In the following sections, we provide evidence from the case study of how firms from four sub-dimensions to the biobased value chain are working towards the circular economy ideal and how digitalization is enabling them to work towards that ideal. By so doing we pay specific attention to the opportunities and challenges arising in such digital transformation processes.

In what follows we will present the key findings from our interviews from each sub-dimension to the bio-based value chain. In so doing we will categorize their experiences in relation to the four stages of digital transformation: Technologies, activities, boundaries and goals.

Packaging

It is virtually impossible to imagine what our lives would be like without the many benefits of packaging. But while the different packaging and single-use items we use on a daily basis are critical in our lives, packaging is also problematic. As the global population grows in size and affluence, the collective demand for packaging materials and the waste we generate as a result will increase dramatically. Packaging deals with addressing this challenge. As such, the packaging processes are complex and as the respondents point out, there are significant opportunities and challenges associated with digitization.

Technologies

The respondents express how dealing with legacy technologies is a challenge. This includes the physical manufacturing machinery as well as the IT-systems associated with them. The portfolio of machinery producing packaging products is overwhelmingly complex:

"This machine is 250 meters long, it is very expensive and if you do one thing wrong there is no redundancy in the process. If an operation does not work correctly, then it brakes. It can be hoses, valves [...] an incredible amount of many different individual small pumps, gears, gearboxes, it's a plethora of different things, and the whole process only works when all those parts work. This means that if on little thing breaks, the whole process goes down, and one hour of production loss can cost SEK 250000."

An important driver for successful digital innovation is to have access to digital data that is structured, standardized and of high quality. However, since packaging machinery is often updated and extended rather than replaced, it may be challenging to retrieve and make use of production data:

"*The data you get from the mills is usually not good, because building a cardboard machine is a continuous process. You first built the machine in the 80s, then you rebuilt one part in the 90s, and in at that time you also introduced a new control system, so you have a newer part while the remaining machine is older. Then you continuously update, and suddenly you have three different suppliers of computer systems, there will be different standards.*"

Concerning AI specifically, companies in the packaging industry express contrasting opinions. While both informants agree on the future potential of AI in improving and automating processes, one found it severely challenging to see that how it could be usefully implemented in the current company setting. Rather, the informant emphasized the importance of instead trying to get more value out of existing technology:

"*I would almost say that it lacks anchoring in reality, at least for the part of the process industry that I see, when big terms around artificial intelligence and stuff are used, and then you see that in reality there are no enabling conditions. The hardware does not fit, the level of education does not fit. There is also no background knowledge […] all these incredible algorithms and machine learning and everything, I think for our process industry, use what you have instead you will go a long way.*"

In contrast, the other company has started to experiment with AI technology:

"We are working with projects where we look offline at datasets and then predict different processes with the help of machine learning, but also online, that is, we try to develop and use models that with the help of machine learning can predict our process outcomes. It always feels like we are going a small step forward and one step back, but then when you look around you see that we are actually doing quite well."

Activities

Working towards the established goals of their core business, activities within packaging companies are largely driven towards the efficient and optimized production of their product.

With long industry traditions, packaging companies are often experienced in the type of innovation activities that are connected to the materials used in their products, and formal organizational structures for innovation activities (such as R&D units) are often designed for that purpose

"…*you could say that when it comes to material development and material innovation we have experience, we have been learning it for a long time, and we have tech centers that work with basic technology development and then we have development groups that sit in the mills and take these technologies to develop products.*"

Boundaries

Interviews revealed how working towards the goals described above also set boundaries for innovation for firms in the packaging industry. The boundaries relevant in this case are those within companies, between companies in the value-chain, and between companies inside and outside the value chain.

As in many other processing industries, the manufacturing of packaging rests on a complex process, advanced machinery, limited redundancy, and any downtime can be extremely costly. This makes it a challenging context for process and product innovation, and companies need to find ways to experiment with, test, and implement new solutions without disrupting the production or refinement process. To that end, one informant described how they address this through compartmentalizing their innovation activities to small and specific application areas and then carefully scale the innovation stepwise:

"*The way forward we see it is to first ensure quality in new measurement technologies and then to push it higher up within very limited applications […] In a very narrow corridor, that's where we should drive these things […] in very narrow segments we can build entire towers, we can go all the way within a certain application, but it first requires that you work with the foundation.*"

Companies in the packaging industries generally have long legacies, and passed actions and practices sometimes result in internal boundaries that come to restrict companies in their efforts to innovate. Departments and units within a company tend to become silos and the communication between them restricted.

"*Where we see that there is a really great potential in sharing data is between the maintenance and the operations sides. They don't talk to each other […] That link inside the mill, I think that cooperation can be improved. Nowadays if you look at the organization of a mill you have site management then you have a production manager then you have a maintenance manager, but those who work with maintenance and operation they don't sit at the same coffee table, they meet at the top in the hierarchy, and then it's usually too late.*"

When it comes to external boundaries, informants express different mindsets concerning the will and value of working with external actors for innovation purposes. Overall, the informants were more positive towards working with actors that belong to the same value-chain. As an example, one of the participants describe how they collaborate with business customers in the value-chain to explore new ways to optimize the flow of material through it:

"When it comes to our large customers, we have close collaborations where the researchers sit side by side trying to solve problems along the value chain, and we also work with data exchange so that we can look at data from our manufacturing and the customer's production and draw conclusions about what is important to the customer's process that we can link to our process and optimize the value chain […] We have a project with customers to continuously upload our data in a common platform, in the cloud as it is called, so that we and customers should be able to look at aggregated data along the entire value chain."

In regards to collaborating with companies outside of the value-chain, the informants point to several challenges. As an example, one informant expresses how external consultants often lack the domain specific knowledge required, and that the products and services they offer are often Ill-suited for the complexities of practice:

"We had maybe 20 meetings with consultants, they had really great mathematical algorithms and stuff […] they wanted to predict the entire production processes, and as I told you, it's a series of connections, an incredible number of processes, and it's just the sum or even the product of the processes that makes the product. It's not that simple when it comes to cardboard and the pulp making process. Of course, with a new machine you have a better starting position, but if you look at the established technology it is rarely that you have the same supplier along the whole machine, and that is where the problem begins."

Goals

Actors within the packaging remain largely focused on becoming more efficient in their traditional core business. Since the products of the actors interviewed are paper-based, and therefore represent a more sustainable alternative to e.g. plastic counterparts, the rationale is that efficiency in their production and refinement leads to sustainability gains.

"Some say it is just a cash cow, but I also think that traditional packaging […] is already creating value for Sweden. If you have good packaging paper, you can replace plastic already. For example, ordinary cardboard and corrugated packaging paper is already part of a bioeconomy, it is environmentally correct in terms of carbon dioxide and currently replaces a lot of plastic."

The focus on the core business is reinforced through an increasing demand for renewable packaging products. As expressed by informants, market demand sets the direction for business and innovation, and currently, packaging based on renewable materials are in high demand:

"On the material side, you can notice an incredible desire for renewable products. For a large part of my professional life, costs have been what set the boundaries for what can be done and not, and then it is difficult to do much else than what was done yesterday: efficient production of paper and cardboard."

While the focus overall is on making production and refinement processes more efficient, there are also examples of actors that through leveraging the opportunities of digital technology have started to expand their core business:

“We have divided our digitization journey into three in three areas that we work with. One that deals with our customer interaction, that is, what our communication looks like with the customers and the partners we have, and the infrastructure and solutions for that. Another area is about internal efficiency, that is what was called automation a few years ago […] The third area we call modern innovation, and that’s perhaps most difficult to grasp […] We enter the value chain with a brand new approach, that is, not just delivering products at one end […] digitization is an important element of that work.”

In sum, packaging is in a digital transformation process with a set of challenges and opportunities associated with each dimension:

Conditions for DT in Packaging		
DT dimension	**Challenges**	**Opportunities**
Goals	• The concept of the traditional core business as inherently sustainable may limit the direction for innovation activities to efficiency gains	• Possibilities to explore new processes, products and services within the boundaries of the core business
Boundaries	• Internal silos may lead to inefficient innovation processes • Opening up to actors outside of value-chain difficult since they lack the domain-specific knowledge required	• Opening up for collaboration with other value-chain actors to leverage existing domain-specific knowledge and resources • Dealing with the criticality and complexity of packing activities through compartmentalizing innovation to specific applications and processes
Activities	• Core activities depend on critical, complex, interconnected and interdependent processes	• Digitization and AI may open up for questioning what constitutes as core activities
Technologies	• Existing infrastructure consists of complex legacy systems and machinery • Investing in the digital technologies that are ideal is demanding in terms of articulating requirements	• There are digital technologies available, and there are competences for articulating requirements to be found in surrounding networks

Table 2: Conditions for digital transformation in packaging

Chemistry

Technologies
Currently, actors in chemicals are primarily exploring digital technologies that may be used to optimize and automate processes, such as sensors, data analytics tools and robots. Further, there are also emerging initiatives involving the use of digital twins. Digital twins are digital replicas of physical materials, products or processes that can be used to experiment with new development approaches or to search for new functionalities within molecules without being exposed to the risks involved in physical experiments:

"For all types of process development, you can leverage computing power to an increasing degree to optimize and calculate in advance so that you do not need trial-and-error in the same way. In research contexts I am involved in, we are looking at both robotization and automation of lab work, you look at the possibility of using digital twins for processes optimization, but also digital twins of products. If you are looking for a specific functionality in a molecule, then it costs a tremendous amount to experiment with billions of different variants before setting up in the lab and doing physical experiments."

In particular due to its potential in storing information about materials and the process through which they travel through the value chain, actors in chemicals are also directing their interest towards the possibilities with blockchain technology:

"There is a lot of talk about the potential of blockchain technology. Even though I don't quite understand how it works, it should enable traceability on a completely new level."

Activities
The main activities in chemicals are still dependent on fossil resources. As expressed by informants, one of the main reasons for this dependency has to do with the cost for acquiring renewable resources and the challenge of competing with fossil-based competitors on the market:

"…about 8-10 percent of our industrial operations are already bio-based today, but if you put that aside, we use fossil raw materials in majority. It's cheap, so the economics of purchasing is a challenge […] you compete with those who make products from fossil raw materials and then you get a worse competitiveness, you earn less money if you buy a more expensive raw material […] It is not always that customers are willing to pay extra, if it is a higher purchase price then you may not get it back from the customer. So the willingness to pay in the market is important."

In order to close current chemical value chains into value cycles, the recycling stage is a key yet challenging issue to solve. Similar as with other sectors described above, the challenge partly arises due to the intermixing of materials that occur as products travel through value chains. Additionally, informants also point to the fact that many products, once initially produced, loose and gain characteristics that make it difficult to reintroduce their constitutive materials into new value cycles. While it may often be technically possible to restore materials, restoration processes are often very resource-intensive and therefore not considered feasible:

“If you look at the largest plants in the chemical industry, they can be adapted to different raw materials […] it will become a great hassle just to keep track of things. This color bucket that we made at one end, is it made of recycled carbon atoms or is it made of bio-based or is it made of fossil or is it something that has first been bio-based and then recycled? So for our industries it will be a hassle with traceability, no doubt.”

"When you are creating new material from original material, this is where it will become a little more complicated [...] circulated polyethylene does not behave like a newly produced polyethylene. Both production properties but also the degradation products are completely different […] and the more times you run your process the more you destroy your original molecule […] it is actually possible to make a whole new material that is like the original, but then you have to break it down to its original constituents so you can build from the ground up, but that is energy intensive and costly.”

In order to solve issues related to the recycling of chemicals, actors are looking into the possibilities of using digital technologies to redesign and improve production processes. One approach to enable better control over the constitution of particular products could be to adopt batch-based production to a wider extent. At the same time, adopting batch-based production infers missing out on the efficiency benefits associated with continuous flow production. As pointed out by both informants, the optimal solution lies in being able to have continuous flow production and still be able to know the constitution of individual products, a solution that may be possible through the use of emerging digital technologies such as advanced sensors and blockchain:

“A large plant may still be consuming fossil raw material in majority, and that will make it difficult to know where the green atoms end up. In some cases, for example when it comes to medicines, you work with batch production […] in larger plants then it is continuous operation and then you do not really know where it ends up. So, then you have to have a system for it, standards or certifications, and that’s where IT can help.”

"[Batch-based production] it is a time thief without resemblance. I am not saying that the product can become very good, but it involves so much manual handling in a way, there is no intelligence in it. But on the other hand, if you have continuous reactions then you need to have measurement systems, you need to have approach technology in a completely different way.”

One additional approach towards addressing the recycling issue is to direct more attention to how digital technologies may be used to improve the process of designing and developing chemicals and products:

"You didn’t design the material on the basis that recycling and reuse would be easy [...] somehow it needs to start with product development or chemical development, that you design for it to be possible to reuse and recycle."

Boundaries

In terms of transforming towards a circular economy, both informants express that much could be gained if chemicals actors collaborated more. So far, however, establishing collaborations across organizations and value chains has been difficult. Besides collaborating with non-competitive actors such as universities, the dominant rationale amongst chemical companies is to retain and protect key processes such as innovation within company boundaries:

“My experience is that it’s difficult, it’s sluggish […] you start by discussing how to distribute patents between yourselves, and nobody wants to give anything away so to speak and then in some way you end up with watching each other instead of succeeding with something amazing […] the ambition is to keep it secret within a tight circle. You can of course collaborate on specific things and details, then you can work with, for example, suppliers or universities, thesis students or industrial PhD students. But there is always some degree of secrecy I would say, and that is certainly good for the company, but in the long run I think you lose more than you gain [...] I think you need to open up more, you need to give something to get something so to say, and you cannot sit on all the skills and competences yourself, I do not think so."

In order to realize the transformation into value cycles, actors in chemicals do not only have to collaborate better amongst themselves but also with actors from other value chains in other industries. Prominently, collaboration across industries and value chains is required to explore new and improved ways to use the waste and biproducts from the production processes of others as well as to find ways in which others can use one’s own. Since chemical actors often operate at the molecular level, they deal with the smallest building blocks that are used and produced by a wide range of industries:

“We use a lot of rubber, we use rapeseed oils, agricultural raw materials such as oils and sugar and stuff and forest debris of different types. We already do that today, but then there is also an interest in using that more. Today, for example, some methanol burns up when making pulp, and our industries use methanol, and then there are questions about whether you can purify the methanol from the paper mills and sell to the chemical companies as a green methanol.”

In order to overcome the institutionalized boundaries between companies and value chains, informants point to the importance of public actors and industry associations such as universities, Vinnova, Bioinnovation to act as boundary spanners. Further, they suggest that in order to initiate and sustain collaboration in chemicals, one needs to work with a stepwise approach, starting with actors in established value chains:

"You have to do this step by step, I think, and then the first thing is that you get stakeholders in the value chain to agree on that now we must help each other, and that there can be no strict boundaries between us and we must have some sort of overlap.”

Should value chain actors be able to better span or dissolve the boundaries between them, informants see several opportunities that are not only associated with the realization of value cycles, but also for improving and expanding the business of chemicals. One such example lies in the potential of enabling customers to tailor the constitution of materials in products that they buy, i.e. so that they can more easily choose and pay for sustainable materials. The purpose of this would be to ensure that customers that pay for sustainable products actually get what they pay for, and that the companies using more expensive sustainable materials are compensated. Not only would this require digital interfaces that enable customers to see available configuration options and what they cost, it would also require systems that would ensure that information is carried both upstream and downstream to all actors in the value chain. Ultimately, this would likely require a substantial reconfiguration of existing value chains and integrations across organizational systems to a much higher degree then what is currently the case in the chemicals sector:

"…when I order something in a web shop, I should on the last page choose what type of raw material I want to pay for and then you can solve it afterwards and balance it all up […] then all the information has to go back in the value chain and if the customer pays a little extra for that, then that money should accompany it to the other end where someone is actually buying that raw material […] it requires digitalization on a completely different level and that information can flow along the value chain and be readily available to producers of input goods, manufacturers and retail, and eventually to the recyclers as well."

Indeed, enabling customers to tailor production to the point where the chemical constitution of products may be configured can only be achieved by substantial investments, coordination and collaboration. Therefore, a more feasible approach could be to imitate that which is currently in place in the electricity market where customers may choose to pay for the production of sustainable energy even though the electricity they use at given points may come from other sources. While this would still require substantive collaboration between actors to agree upon common standards, it would require less of resource-intensive value chain integration and reconfiguration:

"As a consumer, you can order eco-labeled electricity, you can buy it around the clock regardless of the weather because there are agreements and systems in place for what is to be called eco-labeled electricity, wind power and so on. In practice, you might get nuclear power right when you plug in, but everyone has accepted it. In this area there is no such agreement yet."

Finally, informants point to knowledge boundaries as an important issue to address if the chemicals industry is to be able to better use emerging digital technologies to its advantage. Primarily, this concerns a gap between knowledge in the possibilities and limitations of digital technology on one hand and knowledge in chemistry and the specific process involved in the production of chemicals and materials on the other:

"I don't think there is enough competence. To succeed with what we talk about with sensor systems and to handle large amounts of data, you probably need to attain more cross-competence, people who can think a little differently [..] otherwise I will sit in my silo and you sit in your silo, you have to be able to meet. If we say that you are an IT guy who is an expert on computer systems and sensors and you have a small sense of what is happening in the process around chemicals, you have a sense of it but you are not an expert, I think that feeling for each other is needed."

"Chemists and advanced IT staff have completely different language worlds and they have to understand each other. After all, chemists who have read advanced IT are rare, and chemistry is not a compulsory element when reading computer science either, so how should they

understand each other? It is an obstacle from an optimization perspective and it applies to our entire industry."

Goals

Both informants are of the opinion that chemicals is generally a very conservative business area where short term financial planning, legacy mindsets amongst senior management and concerns for disrupting established business and processes hold efforts towards exploring new opportunities back:

"…it's a conservative industry and then you do not want to interfere with your production. At the same time, it must be that you want to improve your production, so it's the chicken and the egg in some way, on the one hand, but on the other [...] Quarterly finances is often a problem. For many of these things we have discussed, you may need a 5- 10-year horizon maybe and then you can't have quarterly finances, unless you decide to set aside so-and-so a lot of money to enable this […] the next generation of company leaders, production managers etc. they need to sit down and say that we will solve this together. In some way, a changed mindset is needed."

So far, the disruptive impact that digital technology has had on other industries such as textiles and fashion has not been experienced in the chemical industry, at least not yet, and this may indeed have served to preserve conservative mindsets towards business. One informant also points to how this may be a generational issue and how younger up-and-coming middle managers may have another perspective:

"Senior management in our industry believes that marketing and sales will continue to be a relationship-based business where customers want to meet and talk to a person, but then if you look at the purchasing staff in their thirties, they start buying more and more online without meeting anyone. That makes you wonder if senior management fully understands what is going on. It can lead to a revolution in the sales and marketing functions as well, and if you were to pull that line of thought out a little, maybe our industries will be just some automatic manufacturing industries of chemicals and materials that do what is ordered without that much thought behind it."

Overall, conservative business mindsets lead chemical actors to engage in innovation that enables them to become better at what they are already doing, i.e. to produce more efficiently and with higher profits. Reflecting on this, one informant expressed how, since all other actors are looking to leverage digital technology to enable more efficient processes, comparative advantage may rather reside in using to do new things differently:

"…how to be able to trace recycled raw materials and how to make them recyclable, I would say that is the area that Sweden should invest in, because when it comes to automation and process development, the whole world is doing it. We may not gain comparative advantage [through automation and process development], *but we are far ahead in thinking about circularity and renewability using raw material from the forest. If you apply these things in these areas, we may be able to develop some kind of unique competence needed in the future."*

Conditions for DT in chemistry		
DT dimension	**Challenges**	**Opportunities**
Goals	• Conservative business logics impede efforts towards exploring new opportunities	• Circularity and renewable resources could become a competitive advantage
Boundaries	• Collaboration in and between value chains is difficult to initiate and sustain • A gap between chemistry and digital technology knowledge impedes innovation	• More extensive collaboration in and between value chains may improve innovation and foster circularity • Collaboration in and between value chains may be fostered with the help of public actors and industry associations
Activities	• Fossil-dependency due to costly bio-based resources and low market returns on bio-based products • Intermixing of materials and altered post-production characteristics makes recycling challenging	• To facilitate recycling and further process optimization, emerging digital technologies may be used to enable traceability and the re-design of materials, processes and products
Technologies	• Promising digital technologies are primarily developed externally to the chemicals industry	• Sensors, data analytics tools and robots carry a potential for further process optimization. • Blockchain carry a potential for enabling the traceability of materials

Table 3: Conditions for digital transformation in chemistry

Wood Construction

Technologies

Similar to other processing industries in Sweden, production processes in wood and construction are digitized to a high degree, and digitization has in turn enabled automation. Besides automation, digitized processes also lead to that data is generated in the different steps of the value chain:

"After all, it's a pretty big development that has been going on for a long time moving us towards a digitalization. It really starts when you make a forestry plan, what is in the forest […] then it comes to the sawmill, and there we measure each log which generates a lot of data, then you have an intermediate layer that you have to keep track of. Then you measure it when it goes into the saw machine, then you make a lot of decisions on how to saw it, and all that is saved, of course. Then you measure the properties of planks and boards, plus you measure production parameters, if we have had a stop time and why. Then you have an intermediate layer afterwards where you collect the logs for drying, a drying process where you continuously measure a lot of variables. And then an intermediate layer after which you measure properties, how it has dried, what twig properties you have. You also have production data there, how fast you drive through the adjustments, what stop time problems you have. And then you go out to the customer when you need to check the business part, that is the average price for different customers, countries, products and so on. So there is no shortage of data in the process."

According to informants, automation with the help of digital technologies is also moving into construction, although it still remains an industry characterized by manual labor. One approach towards circularity in construction can be found in ongoing efforts towards extending existing buildings in cities by building on top of them rather than building new. In order to ensure that they will support additional stories, existing building structures must be understood in detail and reinforced if needed, a process that entails using missing or limited, non-digitized documentation:

"The first challenge is that all the foundation on existing buildings, it is very rare to rebuild or build on something that is only a few years old. The foundation that is from previous construction is, as a rule, 2D and no one projects or draws any construction in 2D right now […] that which is built in the 50's, they are done on well-folded drawings that are stored somewhere, you will get hold of them as well and hope they are preserved."

Due to the lack of legacy documentation, actors in construction are exploring emerging technologies that can sense, measure and analyze existing buildings. For sawmills, recent developments in autonomous vehicles are particularly interesting since they may enable further optimizations of the logistics involved in the production of wood products:

"The sawmills have become much more efficient, but we still drive around the wood with trucks. At present, if you look at the production staff, almost half of the personnel are truck drivers. So there is a potential with autonomous or semi-autonomous solutions where the transport from A to B is made driverless and so you manually handle the trickiest parts."

Activities
Characterizing for the main activities in wood-based production and construction is that they utilize a bio-based raw material where each unit may have unique characteristics, the resource flows are divergent as one type of raw material is processed to produce several heterogenous products, and activities often involve work conducted outdoors and thus exposure to the elements:

"What you can say is the challenge it is, well, that in many ways it is a somewhat special industry. We have a divergent flow, and we buy logs and we produce 3000 products. It's not like buying components and building a car. The raw material is biological, so you have a very large variation in their properties […] we handle 3 million logs a year and no log is really similar to the other. Then we have a large part of the business outdoors. So the combination of being outdoors and the wide variation in properties means that as soon as you get into digitalization and AI and cameras and vision systems and things that are supposed to be autonomous and self-learning, there will be great demands on it. You have different lighting conditions, you have different things to measure, and over the year you will have snow and there are birds flying by like, you name it."

The process of extending existing buildings is different from that of building one from scratch, and therefore, it poses new technological and organizational demands. Since building new stories on top of existing is a relatively uncommon activity, established routines and value chains in the construction industry are not optimized to support that process. Similarly, the many digital tools currently used in construction are primarily designed to calculate and visualize new buildings:

“I'm going to say that if you build a new construction project and you start with a flat on the ground, then you start by examining the soil's condition. It is everyday stuff for all the consulting offices around Sweden that work with such. You can call anyone and say I want a geotechnical survey on this site in that municipality […] Here you can actually start with an existing building so it will be a little different. Do you need to strengthen the existing body then it is not a regular piling but here you need to look where there are pillars? Are there pillars that you can reinforce? Can you put any load-bearing wall somewhere on the existing floors? So that is where it becomes a different technique to use, and I think that there you can probably be a little more manual than you would have been if you had started from scratch. There are quite nice tools otherwise when doing new construction, but there are usually no 3D models on the old one.”

In both wood production and construction, actors are looking into emerging digital technologies that, as they are not primarily developed for the construction industry, may be repurposed to support and optimize processes:

“It will take time before the systems are generally developed for other industries so that they can be used here. If you think you have a forklift that will lift up a 15-ton wood package and it does not always say exactly where it should, and then you put it on top of another package that can sway a little, it is clear that it is well before we are there. On the other hand, being able to have, for example, a shuttle that runs the packages, so that you have a forklift that just lifts off and puts on a shuttle and it gets away with the package, it's a technology that already exists today."

Since many key activities in the construction industry rests on making rule-based calculations and decisions, AI and other forms of automation technologies are particularly interesting with high value potential. However, many current actors in the construction industry also rely on that calculations are made in the traditional way:

"It is also a bit of a threat to those working in the industry right now [...] there is an obstacle there for those who sit and work in a design department who see that they always do the same according to these rules, that they sit and manually figure this out according to this rule based logic […] those people realize consciously or subconsciously that if you do it automatically then that job role also disappears […] much of this industry is built on consultants, I do not know if they feel that it would be a good idea to do this work for 100% of the time. Not if they don't get paid for it."

Boundaries

When it comes to sawmills, their divergent resource flows entail that products and residues from production are sent to different external retailers, other value chains (e.g. those for paper and pulp), and some is also put to internal use:

“Half of the log will be planks and boards, a quarter of the log will be sawmill chips that we sell to the pulp industry. The rest is then shavings and bark, and we use that ourselves as fuel in our boilers that we need to dry wood, and we sell it to district heating plants and others, so that the whole log is used after all.”

Saw mills use one single type of raw material, and efficient resource use along the value chain rests on knowing the unique properties of each raw material unit. Therefore, actors in wood and construction see potential in connecting data flows along the value chain so that the harvesting of raw material, and the production, refinement and retailing stages may benefit from each other:

“What is going on is, above all, traceability through the value chain, to get feedback. There is quite a lot going on now with the new measurement techniques coming. When you reach that level of traceability, you can start to build forecast models with a higher accuracy and thus get better planning tools. More efficient production planning, it is a development step that I believe a lot in, especially when you start to get traceability solutions […] We buy saw timber that has a huge variety. Towards that end, linking the saw and the forest, there is a lot being done and a lot of work is being done, and I think there is something that will be even better [...] to feedback information from the sawmill to improve forecasting models and get more efficient production planning going forward, I believe that."

Since value chains in wood and construction often span across organizational boundaries, efforts towards circularity and more efficient resource use often entail establishing new forms of collaboration with external actors. As an example, one informant expressed how construction actors that become engaged in extending existing buildings may need to find new ways to organize projects temporally, to avoid silos, and to share risks:

“Here you have an existing building that you have to take into account how it is built and then you cannot do these traditional drainpipes where one makes clear and then you leave to the next, but here everyone has to work much tighter […] usually you divide the building into their portions for which you are responsible, and then you take heed that if it is unknown it becomes more risky. But here you almost have to have a new model in certain situations for risk sharing. What if something unexpected happens? How should we distribute it? You almost have to agree on this in advance as best you can."

Goals

Overall, the informants agree on that most innovation efforts in wood and construction are focused on enabling companies to do the things they have always done, albeit faster and more efficient. This does not mean that there are no exceptions, and both informants provide examples of how their companies have started to explore the potential in digital technologies not only for process optimization, but also for new forms of value offerings and capture. Primarily, the development of new products and services can be traced to wider societal transformations such as urbanization and new consumer behaviors and preferences:

“It is a pretty big change over there because in the past everyone lived on their property, but now the urbanization is very noticeable. I can clearly see in this way that many people are

taking over forests now that do not live where the actual forest is, you live in the coastal cities and you have forests that you have inherited inland. And it is clear that then you need completely different services and completely different help in running their forest in a good way."

In construction, extending existing buildings with additional stories is still a relatively uncommon phenomena compared to how many construction projects that aim to build new buildings from scratch. However, not only are such extension projects more efficient in terms of resources used in construction, they also have wider, more systemic, effects:

"To use existing infrastructure and existing buildings to vertically densify cities [...] you can build on existing buildings, so the few green areas that remain are not lost, and you can use the same communications: the same bus or subway system that serves more people, and you don't have the same need to have a car if you can stay centrally."

Further, one informant also expresses how this new type of construction process could provide fertile grounds for entrepreneurship:

"I imagine that there could be room for start-ups to work with surveying and permit assessment of existing buildings to be able to say which ones are suitable for building on. Not only to say that: here the floor plan allows for two more floors, without actually looking a little more at the building and can say that these are very suitable."

In sum, wood construction is in a digital transformation process with a set of challenges and opportunities associated with each dimension:

Conditions for DT in wood and construction		
DT dimension	**Challenges**	**Opportunities**
Goals	• Established business models and practices foster closed boundaries and focus on process optimization	• Urbanization and new consumer behaviors and preferences creates a need for new products and services
Boundaries	• Temporal and organizational boundaries associated with traditional business and operations may hinder the realization of more efficient processes, new products, and new services.	• Interfirm collaboration and achieving traceability through connecting data flows across the value chain may lead to more efficient use of raw material and new forms of value offerings
Activities	• Processes are characterized by a raw material with heterogeneous characteristics, divergent resource flows and exposure to outdoor elements • The process of building on top of existing buildings poses new technological and organizational demands	• Technologies emerging in other sectors may be adapted to align with wood and construction processes • Rule-based processes may be automated
Technologies	• Building on top of existing buildings rests on legacy documentation	• Highly digitized production processes generate data on the

		material throughout the production process • The continuous evolution of digital sensor technologies and autonomous vehicles may be leveraged for further process improvements

Table 4: Conditions for digital transformation in wood and construction

Textiles and fashion

Technologies

In textiles and fashion, several actors are exploring the potential in new digital technologies for printing, tagging, visualizing and sensing with the overall objectives to reduce waste, reduce the use of resources, and to facilitate recycling. Actors are also experimenting with digital platforms to enable sharing of information and facilitate brokering of services within and outside established value chains. Like the other value chains examined in this study, there is also a significant interest in manufacturing robots and their potential for automation.

During and after the Swedish textile crisis during the 60s and 70s, the production of textile and fashion products has to a large extent been offshored to countries with lower wage levels. This implies that while the production of textile and fashion products often rests on the use of different kinds of machinery, these primarily exist in foreign factories.

Activities

In terms of activities, textile and fashion value-chains are complex, often involving several different materials, processes and products. One informant described in a detailed way how different fibers of different origins are mixed and refined through different treatments before a textile or fashion product materializes:

"The fibers we use have different origins. They can come from the forest or from another bio-based raw material, bamboo, eucalyptus or whatever it may be. It can come from the animal kingdom, and it is synthetic fibers from oil or from other sources of protein […] so you start and mix these fibers that have these different origins […] then it goes on to any product or yarn then, it is a very large range, everything from clothes that are for the fashion side and fashion, sports, function, work clothes, to all the technical products that we surround ourselves with […] it is very rarely as a fabric is not treated [...] because of having sprayed or dipped the fabric or coated or laminated it, there are very many different types of processes that start to create this product."

Due to the complexity of their established value chains, actors in textiles and fashion face certain challenges in their use of digital technology to transform into value cycles. For example, while automation through the introduction of manufacturing robots could enable both a more efficient use of resources in production and the generation of data useful for recycling and reintroduction activities downstream, teaching robots the craft of sewing may prove to be challenging:

“If we look at the challenges, it is good to teach a sewing robot to sew a sleeve for example […] partly the fabric is soft, it has different stretchability, and then you have to join two parts [...] things like that can be quite challenging even for an AI because the AI has to train to learn.”

Transformation towards a circular economy also requires connecting the heads and tails of established value-chains by connecting the consumption of products to recycling activities. For textiles and fashion, options for recycling products include converting them into materials that can be used in new value cycles or reintroducing them to the market as second-hand offerings. These activities rest on knowledge about the materials and substances that constitute products, yet after complex and distributed production processes and several years of use, knowing components and their sources becomes nearly impossible. To enable more effective recycling activities and increase circular flows, actors in the textiles and fashion actively search for technologies that may assist in tracking, sensing and sorting:

"There are some technologies that are lacking for us, like sorting technology, today it is manual sorting at first, and then you can sort by color and you can sort by fiber, but you have to be able to sort much more by content [...] traceability, that is a huge challenge. Now I don't know about blockchain and all that stuff, but as I understand it, it can create the opportunity to connect information that makes it easier to reverse this transparency, because we are very dependent on it.”

Hence, the development, implementation and use of more effective technologies would facilitate the tying together of the heads and tails of established value chains since it would provide the means to manage the large bulk of textile material currently on the market. However, in order to foster more sustainable and efficient cycles actor’s also need to find new approaches to product design:

“Whether it is retail or E-commerce, it is always about selling new, that is where you generate the business, it is through the linear […] big transformation, it really happens when you start designing all the products for a circular economy.”

Boundaries

A key characteristic of the textile and fashion industries is the extent to which value chains are globalized:

“Plain clothes or home textiles, there is very little of that manufactured in Sweden. So if we look at the fashion side and also home textiles, then a product may have been in a great many countries and continents before it ends up with us. To mix the fibers and synthetic fibers may be made in one country and the natural fiber in another country and then it is spun together. Then maybe it is woven in another country and then it goes away for preparation in yet another country. Then it goes to yet another country to be cut and sewn, to finally end up in Sweden."

The fact that they are globally distributed implies that different actors in textile and fashion value chains need to comply with different institutional arrangements. A prominent example is the REACH regulation that forces producing and retailing companies within the EU to identify and manage any risks connected to the chemicals used in their products. For Swedish textile and fashion actors, this poses the challenge of having control over imported material in the value chain, but it also manifests in recycling challenges, since it may be very difficult to know what is in the products that consumers themselves order from outside the EU:

“The chemicals legislation REACH, it is primarily for chemicals so it controls very much of the production in the EU, so that textiles produced in the EU may not contain certain chemicals, but if you buy it, or if it comes in and is produced outside the EU, either via regular imports or via e-commerce if the consumer is shopping, then you have no control over the contents."

Since the different raw materials used in textiles and fashion come from a wide range of sources, the transformation towards value cycles requires coordination and collaboration not only across countries, but also across industries. As expressed by the informants, there are also other opportunities to explore associated with inter-industry collaborations, such as finding new ways to reintroduce materials into value cycles within other industries:

“If we look at the start in the value chain, with the fibers, then the forestry industry is an important party, and then we have the furniture industry and the automotive industry that uses our textiles […] shoes are very close, so clothes and shoes, and if we will be able to cope with this with recycling, we will not be able to recycle all our textiles, but there may be something else […] we are very dependent on working across industries and learning from each other because we have come a long way in this […] If you want to get innovation, then the meetings between different industries can be extremely important for that to happen. After all, it is always in the dialogue between people that innovation takes place.”

Informants also made evident how academic institutions can provide platforms that enable actors to span the boundaries between industries as well as those between research and practice. Primarily, informants accentuated the importance of University of Borås and its science park in this regard.

Goals

While a linear logic still permeates much of the business and operations within textile and fashion industries, informants also express how a shift towards more circular business models is gaining interest amongst Swedish companies:

“When we talk about the circular economy, then we have really gone from products to business models. When talking about the circular economy with companies three or four years ago, they thought it was a bit flimsy and that there was no business in it. Today we never get that response, but now you realize that it is business. [A certain fashion chain] has had the business idea that you should be able to buy a new garment every Friday […] which is totally reprehensible […] instead of selling a new garment you can rent a garment instead and make money from it. This means that there are brand new incentives […] instead of running wear and tear we can premium to have quality on the garments so you can reuse them and then rent out, and the more times you can rent out, the more money you earn on the product."

The growing interest in circular business models is connected to an increasing competition from digital actors as well as new behaviors, preferences and demands amongst consumers.

At the same time, the ever-increasing performance and scope of digital technologies combined with their tendency to become cheaper, more available and easier to use enable the exploration of ways to meet emerging requirements and demands. One of the informants foresees how these trends may initiate an extension from the traditional linear logic where business relies solely on selling new products to business models based on more sustainable and service-oriented foundations:

"In the future, there will be three pieces of the cake: it will be new, to repair and to upgrade. It can be anything from reprogramming to adding an embroidery or print or whatever it may be."

Evidently, textile and fashion actors see opportunities in transforming to circular business models, both in terms of improving sustainability and for expanding their means to value creation and capture. At the same time, established firms often rely heavily on traditional linear models to provide the resources necessary to explore new ones:

"You should have respect for that when talking about business models, when you go into the destructive and transformative, it's not just to do it overnight, because you already have a business model that you make money from […] you can't just change your model because then you saw of the branch you are sitting on, and then it is true that hope works."

In sum, textiles and fashion is in a digital transformation process with a set of challenges and opportunities associated with each dimension:

Conditions for DT in textiles and fashion		
DT dimension	**Challenges**	**Opportunities**
Goals	• Most incumbents rely on exploiting linear business models	• Consumer expectations, competition and technological development drives an increasing interest in circular business models
Boundaries	• Globalized and complex value chains lead to a lack of control over the constitution of products	• Collaboration across national and industry boundaries can help create circular flows • Industry associations, academic platforms and research projects span boundaries and create opportunities for innovation
Activities	• Complex and distributed production manifests in recycling challenges • Craft-dependent production leads to automation challenges	• New ways to track, sense and sort may enable the transformation of existing value chains into cycles. • Circular business models support a circular logic to new product design
Technologies	• The technical infrastructure that enable textile and fashion value chains is distributed globally	• Technologies with potential to support the transformation towards circular economy are emerging within and outside the textiles and fashion domain

Table 5: Conditions for digital transformation in textiles and fashion

Looking at all four sub-value chains, digital transformation in these four contexts are diverse, but demonstrate a general orientation in the sense that *technologies* are in place and digitization is well developed in all four contexts, even though AI in particular is not widely used. All key *activities* in all four contexts rely on digital technologies. Having said this, AI provides further opportunities to deepen this development. The boundaries have become more fluid as a result of digitization. However, the stakeholders remain the same even though the fluidity has increased which means there is an opportunity to move outside the traditional value chain for collaboration. Finally, the *goals* are the dimension that is addressed the least in the digital transformation process. The goals largely remain the same, even though there are interesting exceptions.

Discussion

The focus of this study was to advance our understanding of how firms in the Swedish biobased industry seeks to implement the circular economy paradigm by leveraging the value of digitization and AI, and by so doing engaging in a digital transformation process. As such, we investigated digital transformation as a dynamic set of dimensions to enable the development of a process model (Langley, 1999). This approach is consistent with the interpretive approach to qualitative research. During the course of the study, we linked our data to theoretical insights originating from the circular economy and digitization literature.

The transformation to a circular economy ecosystem poses a major challenge for firms in the biobased industry as it requires them to coordinate and manage the resources and incentives of multiple firms. Even if the idea of the enabling role of digitization and AI is widely shared among the firms we investigated, the current knowledge about how such digital transformation should come about is limited. This report makes several contributions towards filling this gap by explaining 1). a maturity model outlining how firms in the biobased industry should address the digital transformation challenge; 2). Collaborative arrangements for leveraging the value of digitization and artificial intelligence in the biobased industry, and 3). recommendations for a thematic call from BioInnovation Sweden.

Opportunities in digitizing the value chain in the biobased industry

Our findings demonstrate how the opportunities in digitizing the value chain in the biobased industry are in place, and the organizations we interviewed have begun to explore these opportunities.

There is a widespread understanding among the firms interviewed that sustainability represents a critical issue for the individual firms as well as the industry as a whole. As illustrated in figure 5, all firms we interviewed pointed at digitization as a tool with which to address the challenges. Related to the *production of raw material*, there are efforts made to build feedback loops from the *refinement of raw material* to build on that data in the production. One example of this mentioned above is how sawmills are exploring the possibilities of using data generated from the processing of raw material in the saw line to better understand how to efficiently harvest and use the raw material. The opportunities associated with working with analytics in this manner are touched upon but largely represents an untapped opportunity. Working with this in a strategic way would entail embedding smartness into products which would enable smarter production, use and repair. As an example, textile and fashion companies are exploring ways to modularize their products and embed within them digital capabilities to facilitate personalization and reuse. Similarly, digitized products and digital services for the *consumption* phase would enable richer datasets that would enable feedback loops in the value cycle. Finally, traceability throughout value cycles represents a key enabler for the *recycling/reintroduction* phase. As emphasized by several informants, the ability to trace materials and products through digital means would be important in facilitating disposal and reintroduction of materials into secondary value cycles, but it is also associated with the potential to enable the creation of new circular business models.

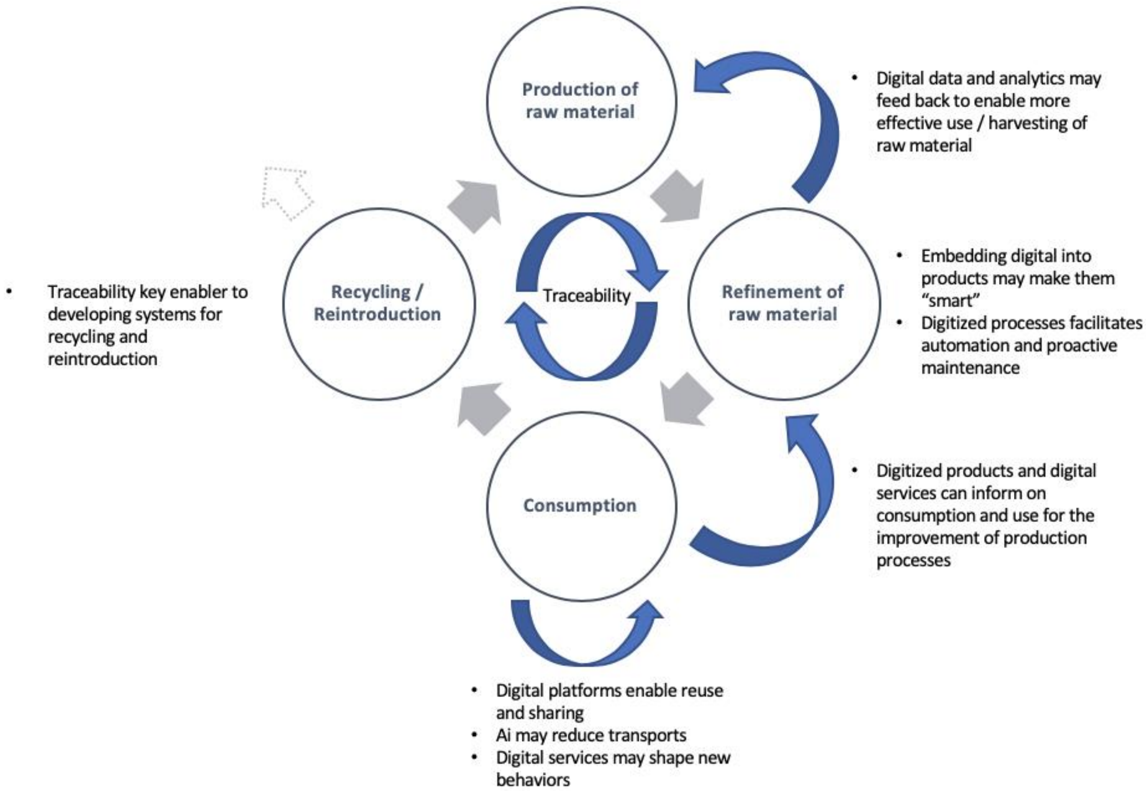

Figure 5: Digitization opportunities in the biobased industry

In sum, the opportunities associated with digitizing the value cycle are mainly untapped at this point. As such, figure 5 is not established practice but rather a model that the firms strive for, albeit with varied success. There are some promising examples of firms leveraging digital technologies to embrace these opportunities. There is also a widespread awareness of the opportunities and a willingness to explore them in the future.

Digital Transformation: A Maturity Model

Firms in the biobased industry are facing the challenge of making the transition to the circular economy paradigm. The literature on the circular economy literature remains conceptual and mainly provides discussion on broad steps to make our world more sustainable. Our study directly addresses the current lack of knowledge in this domain by presenting a four-stage framework to describe how firms are engaged in a digital transformation process in which they seek to leverage the value from digitization and AI. Identifying and exemplifying how firms work to implement the circular economy paradigm can support the large-scale adoption of these principles in the shift towards a sustainable biobased industry.

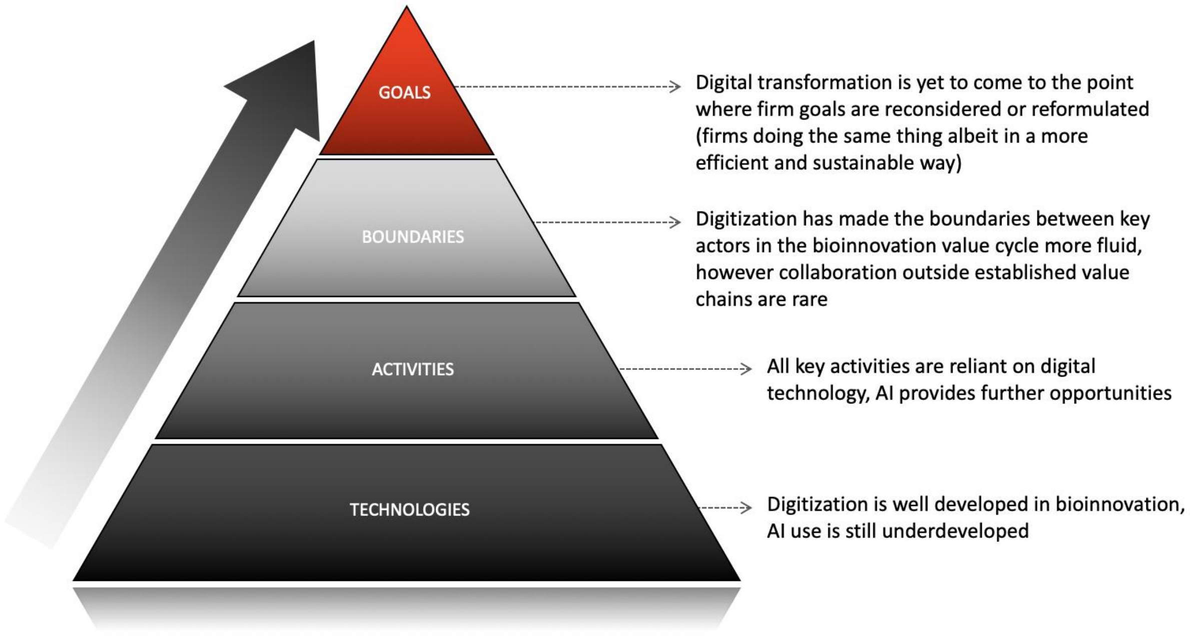

Figure 6: Digital transformation in the biobased industry

The firms in the biobased industry are all engaging in a digital transformation process. As such, all four sub-domains are making progress and are aware of key challenges. Following the trajectory of technologies-activities-boundaries-goals, it is very clear from the interviews that digitization in general has been working well for a long time, but the opportunities in AI are yet to be developed. While all key activities are dependent on digitization, AI represents the next step to take. As a whole, the digital transformation process is yet to come to the point where prior goals are redefined and new goals are realized. Indeed, anecdotal evidence indicate what could be emerging exceptions to this, primarily evident in actor initiatives towards leveraging digitization to fundamentally reshape business models in textiles and fashion, yet the biobased industry remains focused on legacy goals overall. In order to do so – in order to capitalize from the value offered by digitization and AI – collaborative arrangements are needed.

Collaborative arrangements for leveraging the value of digitization and artificial intelligence in the biobased industry

The success with digitization for any firm partly depends on how effectively it co-opts the complementary capabilities, resources, and knowledge of the network of firms, institutions, and individuals (Williamson and De Meyer, 2012; Westergren et al., 2019). Indeed, the capability to catalyze the emergence and guide the development of a vibrant ecosystem offers increasing potential as a powerful source of competitive advantage. This potential has already been proven in high-technology industries (Jonsson et al., 2018; Westergren et al., 2019).

Prior research has identified that a key barrier for innovation in the biobased industry is that firms often focus too heavily on inter-firm interests instead of adopting a holistic perspective of the biobased ecosystem that can lead to higher innovation and value creation for the industry as a whole but also for individual firms (Sjödin et al., 2016). As shown above, the existence of myopic behavior amongst actors is confirmed through several interviews that express how the logic of isolating one's own business, operations and innovation is dominant, most prominently so in chemistry and packaging .The lack of a holistic perspective within the biobased industry is problematic since the shift to the use of new digital technologies often leads to ambiguity in roles and a lack of clarity on who should take what role in value cocreation (Westergren et al., 2019) which requires focal actors to take a more active role in orchestrating the ecosystem (Leven et al., 2014). As such, we recommend casting a wider net to focus not only on the internal issues in a firm but to embrace an ecosystem thinking which includes collaborating with partners, vendors and customers. This was asked for in our interviews, and it is critical to find a way forward with this particular challenge. In addition, collaborating with other SIPs and academia is a useful way forward. Specifically, we recommend three main collaborative arrangements for enhancing the efforts in digitization and AI:

- **Engage with and learn from best practices**

In order to expand current thinking in the biobased industry, best practices are necessary. Accessing a portfolio of best practices can create strategic advantage, which is especially important in relation to an issue as complex as AI. We see this dynamic in the process industries as well, where there is time and energy spent on today's best practices, but also an increasing amount of time spent looking around the corner to understand what is coming next.

We recommend a collaboration with other SIPs in this effort as the similarities in the challenges are striking (Blue Institute Group, 2019). The biobased industry firms will only be able to capture the full potential of the digital transformation by cooperating closely with each other, and with firms from other relevant industries, due to at least three factors:

- *Common challenges:* The firms face many similar challenges, such as the need to reskill the workforce.
- *Scale effects:* Together, the firms represent a powerful actor which is highly capable to negotiate good deals with technology vendors.
- *Similar starting points:* The biobased industry firms have high levels of market openness, similar levels of digitization, and cultural and historic commonalities with firms represented in the other SIPs.

As such, engaging with best practices is best done in collaboration with the other SIPs.

- **Build the capability to articulate requirements to technology vendors**

Today, digital capabilities are a prerequisite to compete in the long term for firms in the biobased industry. While there is a widespread understanding of this among the firms, many firms seeking to go digital are still unclear about the best way to set up their IT organizations and develop the tools and talent required to manage digital information and establish and maintain online services and automated processes. What must be acknowledge at the outset is that many of the critical resources required to facilitate digital transformation will not be available in-house.

To better compete, firms in the biobased industry need to adopt a dynamic approach to accessing digital capabilities from outside the organization. Specifically, we believe firms must take a closer look at their requirements specification practices.

Firms undergoing traditional business transformations have tended to adopt a sequential approach to acquiring the technologies they need. Technologies are brought in based on initiatives that are rigidly scheduled: the starting point is the firm goals, which then is broken down into key boundaries (which unit does what and what are the relations with outside firms?), and then into key activities. Requirements for what technologies are needed is then articulated from this top-down process. This approach is inadequate for digital transformations. Instead, the opposite process is articulated, which sets a whole new agenda for requirements articulation:

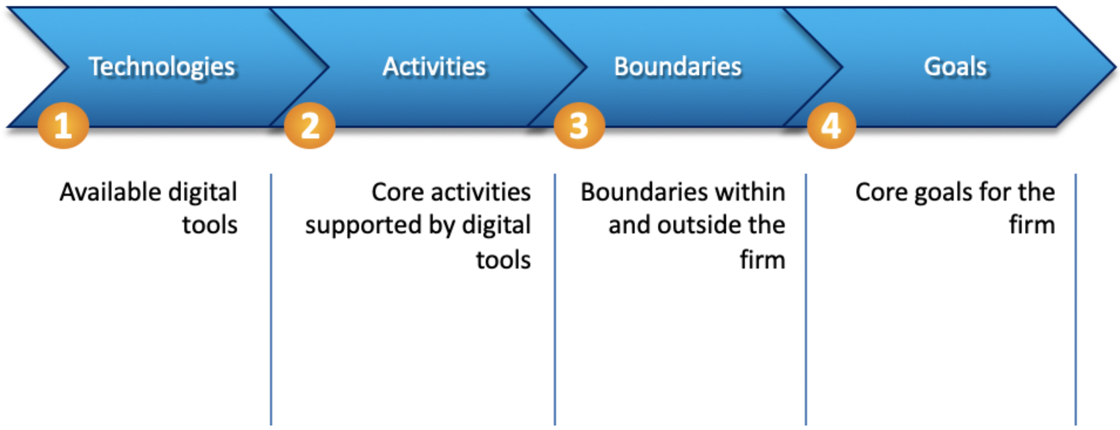

Figure 7: The digital transformation process

Following this process, firms will ideally be able to scale up nascent digital initiatives quickly and sustainably: accelerating the use of emerging technologies, aligning fragmented activities, and developing vendor relationships that can evolve with their changing needs. The problem firms are faced with is that this requirements articulation is new and a collaborative process in which firms collaborate with this – within the biobased industry but also with other SIPs – is necessary.

- **Build need-based educational efforts**

Digital transformation and the integration of digital technologies such as AI in the firms in the biobased industry is not a choice, but a necessity. For the firms who wants to harness the power of these disruptive technologies to improve operations and increase the business value derived from these technologies, education is key.

But even though all firms agreed that education is a key for successful digital transformation, the right competence is in short supply. The distinctive experts required to develop successful digital transformation include managers who are literate in cutting-edge technologies that can be used to reshape the consumer decision journey, experienced business and data analysts who can extract useful insights from customer data, and user experience experts and design-oriented content managers who can ensure that the offerings will appeal to target audiences. This is not currently the situation among the firms, and as such we recommend engaging with the universities to address this concern. Two specific efforts are recommended:

- Executive educational programs hosted by university partners, based on the specific needs among the participating firms
- Experimentation platforms for the participating firms to engage with new digital tools

Taken together, these efforts represent the first steps towards successful digital transformation.

Guidelines for a thematic call from Bioinnovation Sweden

For a thematic call from Bioinnovation Sweden, it is critical to address the needs among the participating firms. Specifically, voices are raised during the interviews that the collaboration with academia does not always work as well as one would expect. The gap between research and practice is mentioned throughout the interviews and is something that should be reflected in the call. As such, we recommend considering the following themes:

- **Practice-based scholarly projects**

  In order for the firms to get maximum benefit from a call we recommend a theme focusing on practice-based scholarly projects. Given that research and practice operate under different logics we suggest an approach where this gap is bridged by establishing projects addressing the key concerns for the firms, and that a scholar in partnership with a firm works in a practice-based situation at the actual firm. This is an emerging opportunity, for instance at Umeå University the industrial research school focuses on this very issue by accepting researchers to the industrial research school program to work for four years to answer a research question that is both of mutual interest to the partners and important to future scholarly progress. These projects maintain a high level of scientific quality and a practical value for the participating firms. A 50% funding is typically possible to gain from the universities.

- **Enhancing the value from data analytics**

  A key outcome from investments in digitization and AI is to enable the firms to engage in big data analytics. It has been demonstrated that firms that developed higher big data analytics capabilities increased their performances, and that knowledge management capability plays a significant role to get the value one wants (e.g. Ferraris et al., 2018). Therefore, the interplay between information technology systems and knowledge management processes is likely to speed up the digitalization journey (Del

Giudice & Della Peruta, 2016; Scuotto et al., 2017). Despite this, we still know very little on how firms may implement knowledge management practices to facilitate the value drawn from data analytics. We recommend a theme that addresses this challenge, and focuses on how we can effectively organize around data analytics efforts.

- **Development of risk assessment capabilities**

  Given the focus on, and investment levels in, digitization and AI, the assumption behind this report is that the key prerequisites required to support growth in digitization and AI must be understood and addressed. Regardless of specific context in the biobased economy, digitization and AI is exploding, and it is not likely to slow down over the next several years. While this rapid growth is creating a hotbed for innovation, it is also presenting growing challenges for the protection of digital information. The vulnerability challenges that the world is facing on the Internet are related to the growth in digitization and AI, and specifically many "smart" IoT devices are highly vulnerable and open for different types of attacks. The Cyber security company Symantec Corporation has concluded that most IoT devices are scanned by various cybercriminals approximately every two minutes. This means that an unprotected IoT device could be breached within minutes of going online (Symantec Security Response, 2016). This is critical for firms in the biobased economy to consider when investing in digitization, AI and IoT. Against this backdrop, we recommend a theme focusing on developing risk assessment capabilities as the efforts in digitization and AI are increased. This entails the need to identify, assess, and reduce risk associated with the protection of digital data among the firms.

Taken together, these three themes cover well the barriers to digital transformation identified in this study, and are targeted efforts to address them in a thematic call from Bioinnovation Sweden.

Conclusions

The transformation to a circular economy ecosystem poses a major challenge for firms in the biobased industry. Our study demonstrates that the idea of the enabling role of digitization and AI is widely shared among the firms we investigated, but the current knowledge about how such digital transformation should come about is limited. As such, there is an urgency in building relevant knowledge among the firms in the biobased industry. Clearly, the rise of machines capable of carrying out tasks that require high levels of innovation, planning, and empathetic behavior (e.g. the "strong AI") is yet merely the subject of speculation, and not to be expected in the near future (Russell & Norvig, 2016). Key aspects of complex decision-making – such as issues of ethical trade-offs and deep innovation are inherently complex in nature and thus too complex to automate. Yet, the current debate on AI use often confuses the two separate issues of management *by* AI (i.e., the use of AI as a tool to automate organizational processes) and management *of* AI, and tends to focus on the former at the expense of the latter.

As made evident in this report, firms in the biobased economy face both common and unique challenges and opportunities in transitioning to a circular economy. It is surprising and unfortunate that many efforts in articulating strategies for transitioning to a circular economy fail to recognize the role of digitization (see e.g. IVA, 2020). It is a core argument in this report that digitization and AI are key enabling factors in the realization of value chains into value cycles. For example, its inherent capability to produce, gather and analyze data lends digital technology with the abilities to inform and to automate (Zuboff 1985). It is through the mobilization of such basic abilities that it may be used to trace material throughout production and consumption and to reduce resource use in manufacturing processes. However, while digital technology is necessary, it is insufficient to realize the substantial transformation processes required in the transition from value chains to value cycles.

Indeed, our study shows that in solving the challenges that oppose circularity, the most acute limitations are not in the capabilities of digital technologies per se, but rather in the capacity of social systems to design, develop, implement and use them for new purposes. In line with recent research (Skog 2019), our observations confirm that it is not until human actors are able to breach the taken-for-granted boundaries and the basic goals of years of successful practice that they are able to realize and mobilize digital technology's more enhanced abilities and truly transform.

Digital technology's ability to enable combinatorial and distributed innovation has been increasingly recognized in existing research (Henfridsson et al., 2018; Nambisan et al., 2017; Yoo et al., 2010). Demonstrated by platforms such as iOS and Android, digital technology offers unforeseen possibilities to combine physical and digital resources in the creation of new products and services. These platforms also demonstrate the substantial value that can be harnessed when companies decide to open up established boundaries and distribute value creation and capture to companies and customers beyond existing value chains. However, as this study indicates, actors in the bio-based industries tend to retain both their current business and their innovation activities within company or value-chain boundaries.

The increasing diffusion of digitalization and AI in the biobased industry can be expected to bring about a number of relevant transformations. By mapping the framings of the challenges that emerge alongside digitalization and AI adoption in the biobased industry, we aimed at providing a first step towards a more systematic investigation of its complex implications. From this perspective, understanding the hurdles associated with transforming value chains into value cycles with digital technology is an inherently sociotechnical issue that can only be achieved through understanding the complexities of practice. In particular, it relies on understanding how humans engaged in practice interact with, make sense of, mobilize, and change technology as well as the activities, boundaries and goals that shape both how they work and how they use technology.

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