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Assessing emerging technologies for sustainability transitions: An analysis from a technology, company and ecosystem perspective

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Abstract

Understanding the role of technological innovations has always been a central concern of strategic management research. Specially to address the current challenges of the 21st century, such as climate change or environmental degradation, new technologies, in particular sustainability-oriented technologies (SOTs) are emerging. However, in the case of emerging SOTs that are often interdisciplinary, potentially induce systemic changes and are in strong competition with prevailing, less sustainable technologies, technology assessment and technology commercialization are challenging. As industry plays an important role in identifying and evaluating emerging SOTs, it is important to better understand industry stakeholders' perceptions and to support them in driving sustainability transitions with the help of technological innovations.

Thus, this thesis is motivated by the main goal *to foster the transfer of emerging SOTs from science to industry to eventually contribute to the transition of current business towards greater ecological sustainability*. This thesis uses concepts from strategic (technology) management, strives to obtain criteria for the evaluation of emerging SOTs from business perspectives and seeks to derive strategies how companies can position themselves in an emerging business ecosystem driven by new technologies. In order to achieve these objectives and given that technology assessment requires different perspectives, this dissertation conducts three empirical studies:

From a technology perspective, the first study proposes a semantic similarity analysis approach of patent and publication documents. Secondary data sources, such as patents and publications, are valuable data to gain a comprehensive overview of emerging technologies. Applied to the highly dynamic case of phosphorous recovery as an emerging SOT field, a newly developed indicator (the number of semantically similar publications per patent belonging to a specific sub-technology) contributes to the identification and evaluation of emerging technologies in the context of sustainability transitions.

From a company perspective, the second study analyzes what different actors along the value chain look for when selecting SOTs. This study draws upon a group concept mapping approach based on a group discussion and a subsequent sorting and rating process of selection criteria. Applied to the case of the bio-based economy, this study seeks to aggregate the perceptions of four different stakeholder groups along the value chain, i.e., (1) agricultural and feedstock, (2) (bio)-chemical, (3) consumer industries and (4) consultancies and networks. The study derives 11 different categories subsuming 59 criteria that have been perceived as relevant when

selecting SOTs. Results show that selection criteria related to the future competitiveness, the public perception and the technical feasibility of the technology are perceived as highly relevant for most actors when selecting SOTs.

Eventually, from an ecosystem perspective and knowing that many SOTs reveal systemic characteristics, the diffusion of SOTs from niche innovations to a new regime and hence, sustainability transitions are only possible if many actors jointly create value. Applied to the case of digital technologies, as an example of emerging SOTs in the agricultural industry, the third study draws upon information system literature, investigating the less explored concept of control points that constitute value creation and capture mechanisms in the dynamic bargaining situation of emerging digital business ecosystems. It contains a multiple-case study with 15 companies, industry associations and consultancies in the digital agricultural ecosystem. The study identifies 13 different control points categorized into technical and strategic ones and 2 institutional boundary conditions emerging on the way from the traditional linear value chain towards digital business ecosystems, resulting in the development of different control point strategies.

The contribution of this thesis is multifold and results are discussed to the technology, company and ecosystem perspective respectively. This thesis contributes to technology forecasting of emerging technologies in general and emerging SOTs in particular. Accordingly, results of this dissertation contribute to the evaluation of growth and coherence of emerging technologies. Further, they contribute to sustainability transition literature by providing, first, a conceptual framework for relevant selection criteria of SOTs from a value chain spanning perspective, second, areas of coherence vs. non-coherence in technology evaluation across different value chain actors and third, evidence that competitive advantages within business ecosystems rely on a company's ability to connect to other actors and to complement own resources, while eventually contributing to an overall ecosystem value proposition. This thesis, moreover, generates important practical implications for managers and policymakers. Results show that regulatory certainty and planning security regarding the economic viability of the technology, independent of subsidies and, in the event of changing regulations are important aspects to be considered regarding the regulatory framework of SOTs. In addition, results allow for stakeholder targeted support initiatives to facilitate the technology transfer in the context of sustainability transitions.

Zusammenfassung

Die Rolle technologischer Innovationen zu verstehen, war schon immer ein zentrales Anliegen der strategischen Managementforschung. Vor allem in Anbetracht der großen Herausforderungen des 21. Jahrhunderts, wie Klimawandel und Umweltzerstörung, entstehen verschiedene nachhaltigkeitsorientierte Technologien (SOTs). Im Falle neuer SOTs, die oft interdisziplinär sind, systemische Veränderungen bewirken und in starkem Wettbewerb mit vorherrschenden, weniger nachhaltigen Technologien stehen, stellen Technologiebewertung und -vermarktung jedoch große Herausforderungen dar. Da die Industrie eine wichtige Rolle bei der Identifizierung und Bewertung neu entstehender SOTs spielt, ist es einerseits wichtig, die Wahrnehmungen von Industrieakteuren zu verstehen und andererseits sie dabei zu unterstützen, die Nachhaltigkeitstransition mit Hilfe von technologischen Innovationen voranzutreiben.

Das Hauptziel dieser Arbeit ist, *den Transfer von neu entstehenden SOTs von der Wissenschaft in die Industrie zu fördern, um so einen Beitrag zur Nachhaltigkeitstransition der heutigen Wirtschaft zu leisten*. In dieser Arbeit werden Konzepte des strategischen (Technologie-) Managements verwendet, um Kriterien für die Bewertung neu entstehender SOTs aus Unternehmensperspektive zu erhalten und Strategien abzuleiten, wie sich Unternehmen in einem neu entstehenden, von Technologien angetriebenen Business Ökosystem positionieren müssen. Da Technologiebewertung verschiedene Perspektiven erfordert, werden in dieser Dissertation drei empirische Studien durchgeführt:

Aus technologischer Sicht wird in der ersten Studie ein Ansatz zur semantischen Ähnlichkeitsanalyse von Patent- und Publikationsdokumenten entwickelt. Sekundäre Datenquellen wie Patente und Publikationen liefern wertvolle Daten, um einen umfassenden Überblick über neue Technologien zu erhalten. Angewandt auf den Fall der Phosphorrückgewinnung trägt der neu entwickelte Indikator (die Anzahl semantisch ähnlicher Publikationen pro Patent, das zu einer bestimmten Untertechnologie gehört) zur Identifizierung und Bewertung neuer Technologien im Kontext von Nachhaltigkeitstransitionen bei.

Aus Unternehmensperspektive analysiert die zweite Studie, worauf verschiedene Akteure entlang der Wertschöpfungskette bei der Auswahl von SOTs achten. Sie nutzt den Group Concept Mapping Ansatz, der auf einer Gruppendiskussion und einem anschließenden Sortier- und Bewertungsprozess von Auswahlkriterien basiert. Angewandt auf den Fall der biobasierten Wirtschaft aggregiert diese Studie, die Wahrnehmungen von vier verschiedenen Stakeholder-Gruppen entlang der Wertschöpfungskette, d.h. (1) Agrarindustrie, (2) (bio)-chemische Industrie, (3)

Konsumgüterindustrie und (4) Beratungsunternehmen und Netzwerke. In der Studie wurden 11 verschiedene Kategorien gebildet, die 59 Kriterien umfassen, die bei der Auswahl von SOTs als relevant erachtet wurden. Die Ergebnisse zeigen, dass Auswahlkriterien, die sich auf die künftige Wettbewerbsfähigkeit, die öffentliche Wahrnehmung und die technische Machbarkeit der Technologie beziehen, von den meisten Akteuren als sehr wichtig für die Auswahl von SOTs angesehen werden.

Aus Ökosystemperspektive und in dem Wissen, dass viele SOTs systemische Merkmale aufweisen, ist die Diffusion von SOTs über Nischeninnovationen zu einem neuen Regime und damit Nachhaltigkeitstransition nur möglich, wenn viele Akteure gemeinsam Wert kreieren. Die dritte Studie stützt sich auf den Fall digitaler Technologien als Beispiel für aufkommende SOTs in der Agrarindustrie und untersucht das Konzept der Kontrollpunkte, die in digitalen Business Ökosystemen die dynamischen Wertschöpfungs- und Werterfassungsmechanismen darstellen. Sie enthält mehrere Fallstudien mit 15 Unternehmen, Branchenverbänden und Beratungsunternehmen im digitalen Agrarökosystem. Die Studie identifiziert 13 verschiedene Kontrollpunkte, die in technische und strategische unterteilt werden, sowie 2 institutionelle Rahmenbedingungen, die sich auf dem Weg von der traditionellen linearen Wertschöpfungskette hin zu digitalen Business Ökosystemen ergeben.

Die theoretischen und praktischen Implikationen dieser Arbeit sind vielfältig. Die Dissertation trägt zur Bewertung des Wachstums und der Kohärenz von neuen Technologien bei. Darüber hinaus leistet sie einen Beitrag zur Literatur im Bereich der Nachhaltigkeitstransition, indem sie einen konzeptionellen Rahmen für Auswahlkriterien von SOTs aus einer wertschöpfungskettenübergreifenden Perspektive liefert, Bereiche der Kohärenz bzw. Nicht-Kohärenz bei der Technologiebewertung über verschiedene Akteure der Wertschöpfungskette hinweg aufzeigt und den Nachweis erbringt, dass Wettbewerbsvorteile innerhalb von Business Ökosystemen auf der Fähigkeit von Unternehmen beruhen, sich mit anderen Akteuren zu vernetzen und die eigenen Ressourcen zu ergänzen, während sie letztendlich zu einem Wertversprechen für das Ökosystem beitragen. Zudem ergeben sich aus dieser Dissertation wichtige praktische Implikationen für Manager*innen und politische Entscheidungsträger*innen. Die Ergebnisse zeigen, dass Regulierungs- und Planungssicherheit in Bezug auf die wirtschaftliche Tragfähigkeit der SOT, unabhängig von Subventionen und sich potentiell ändernder Vorschriften, wichtige Aspekte sind, die bei regulatorischen Rahmenbedingungen berücksichtigt werden müssen. Des Weiteren ermöglichen die Ergebnisse gezielte Unterstützungsinitiativen für Interessengruppen, um den Technologietransfer im Kontext von Nachhaltigkeitstransitionen zu erleichtern.

Content

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List of acronyms

AI	Artificial Intelligence
CPC	Cooperative Patent Classification
DSS	Double-Single-Sided
EPO	European Patent Office
EU	European Union
EVP	Ecosystem Value Proposition
GCM	Group Concept Mapping
IO	Industrial Organization
IoT	Internet of Things
IPC	International Patent Classification
LCA	Life Cycle Assessment
OECD	Organization for Economic Co-operation and Development
PL	Patent Lane
R&D	Research and Development
RBT	Resource-Based Theory
RQ	Research Question
SDG	Sustainable Development Goal
SOI	Sustainability-Oriented Innovation
SOT	Sustainability-Oriented Technology
TIS	Technology Innovation System
UN	United Nations
VP	Value Proposition
WoS	Web of Science

1 Introduction

1.1 Research problem and objectives

Understanding the role of technological innovations is a central concern of strategic management research (Zahra & Al, 1994). Since the 20th century already, the identification, tracking and conceptualization of ideas on emerging technologies have been subject of research, as emerging technologies are considered as one of the core drivers of economic growth (Burmaoglu, Sartenaer, & Porter, 2019). However, an emerging technology has not yet necessarily demonstrated its future value and market potential, as it often emerges on science level and is at an early stage of its development process (Cozzens et al., 2010; Stahl, 2011). Emerging technologies might include radical innovations or technologies emerging through the convergence of previously different research streams and thus, have the potential to change existing industries (Day & Schoemaker, 2000; Sick & Bröring, 2022). Hence, for companies that means, to ensure long-term competitiveness, they need to assess emerging technologies from different perspectives and take into account interdependencies between influencing factors (Heger & Rohrbeck, 2012).

Especially to address the current challenges of the 21st century, such as climate change or environmental degradation, new technologies, in particular *sustainability-oriented technologies* (SOTs) are emerging (Frondel, Horbach, & Rennings, 2007; Rennings, 2000). They pose specific challenges for companies and their strategic technology and innovation management that is contingent on the circumstances of an unstable environment (Bröring, Laibach, & Wustmans, 2020; Tidd, 2001). For example, to reach a sustainability transition from a fossil-based to a bio-based economy, current systems, such as the transport, energy or agri-food system need to undergo fundamental structural changes including the implementation of systemic technological innovations (Elzen, Geels, & Green, 2004; Geels, 2011; Stark et al., 2022; van Bergh & Bruinsma, 2008).

This process of sustainability transition is illustrated in Figure 1.1 from the multi-level perspective (Geels, 2011; Geels & Schot, 2007). Sustainability transitions are defined as "long-term, multi-dimensional, and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption." (Markard, Raven, & Truffer, 2012, p. 956). Transition processes, in general, include developments on the socio-technical landscape, i.e., 'macro'-, level that put pressure on the existing socio-technical regime on the 'meso'-level including existing markets and user preferences, policy, science, technology and industry (Geels, 2011). On the 'micro'-level, niche innovations, which are characterized as protected spaces, i.e., specific application domains or markets, in which radical innovations can develop without being in direct competition with the existing regime, emerge (Kemp, Schot, & Hoogma, 1998). Technological innovations are considered as one of the drivers initiating sustainability transitions (Geels, 2002; Hausknost, Schriefl, Lauk, & Kalt, 2017; Laibach, Börner, & Bröring, 2019). Accordingly, SOTs can contribute to the technological transition of the fossil-based towards the bio-based socio-technical regime from the bottom up (Markard et al., 2012). To visualize this process and the research focus of this dissertation more clearly, Figure 1.1 extends the original framework on technological transition by Geels (2002) and Geels and Schot (2007) by another sub-level of emerging SOTs. It shows that before niche innovations - already incorporating a certain maturity level - emerge, new technologies, in this case SOTs being more ecologically sustainable, are emerging. Some of these emerging SOTs will complement or substitute the old technology indicated in bold in the fossil-based socio-technical regime.

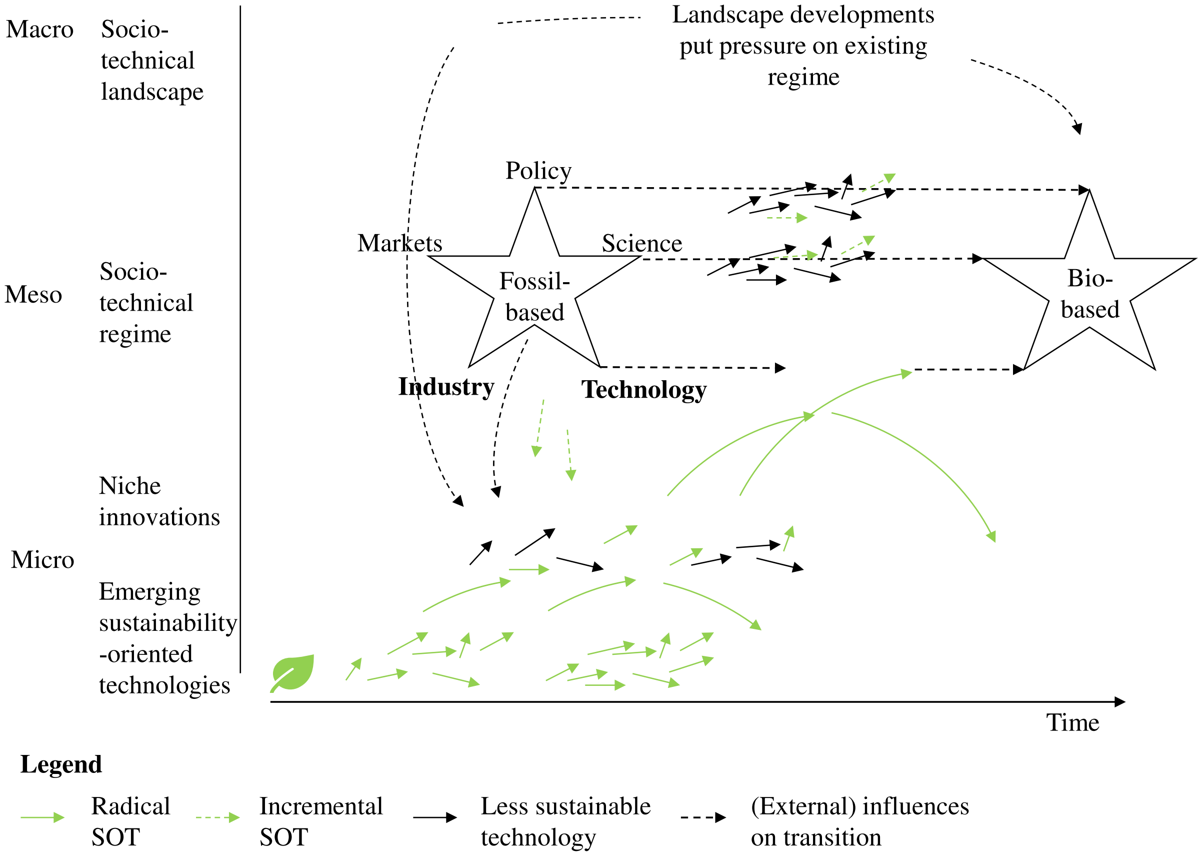

Figure 1.1: The multi-level perspective on transitions based upon the case of the sustainability transition of the fossil-based towards the bio-based socio-technical regime. Source: adapted from Vandermeulen, Van der Steen, Stevens, and Van Huylenbroeck (2012) and Geels and Schot (2007).

However, these SOTs, once they penetrate the market environment called *niche innovations* or *sustainability-oriented innovations* (SOI), have either a competitive or symbiotic relationship with the existing regime (Geels & Schot, 2007). The arrows indicate that only some of these SOTs will result in niche innovations, of which, in turn, only a portion will be implemented in the new regime. The green arrows in Figure 1.1 indicate the new technologies, (i.e., SOTs) that are considered environmentally sustainable. The green dashed arrows on the meso-level reflect SOTs, which result from incremental improvements of existing technologies. The green arrows, from the micro-level, represent SOTs resulting from radical innovations that are the focus of this dissertation. The likelihood that radical SOTs break through and replace the existing regime depends on the landscape pressure and thus, the stability of the existing regime (Geels & Schot, 2007). Further, from a general technology management perspective, a new technology may only be viable if it can outperform existing technologies on some performance criteria, such as functionality or cost, and thus achieve a relative advantage. Usually, a new technology does not initially dominate an established technology in its primary domain of application (Adner & Levinthal, 2002).

Accordingly, many SOTs are still in the laboratory phase and face the challenge in penetrating the mainstream market (Bohnsack, Pinkse, & Kolk, 2014; Carraresi, Berg, & Bröring, 2018), although a sustainability transition is only possible, if potential technologies diffuse from scientific knowledge into marketable processes (Geels & Schot, 2007; Vandermeulen et al., 2012). Transition research claims that scientific knowledge, engineering practices and process technologies are embedded in a system of intertwined skills and expectation of technology users, with institutions and general infrastructures (Kemp et al., 1998). Accordingly, many SOTs reveal characteristics of systemic innovations (Kiefer, Carrillo-Hermosilla, & Del Río, 2019). Fichter and Clausen (2021) show that depending on the sector the diffusion of environmental innovations is considerably low. Especially, the agricultural and food industry suffers from low diffusion rates (Fichter & Clausen, 2021). For example, an EU report shows that the commercialization of research efforts in industrial biotechnology are particularly challenging (Izsak et al., 2020).

Often, it is claimed that policy plays a crucial role in supporting the diffusion of SOTs and shaping sustainability transitions (Fichter & Clausen, 2021; Geels, 2011; Markard et al., 2012). However, beside other regime actors, companies, i.e., industry, play a crucial role in the market implementation of SOTs and thus, in sustainability transitions (Bähr & Fliaster, 2022; Köhler et al., 2019). On the one hand, it has been criticized that firms rather focus on improving their firm-level sustainable behavior than pushing radical changes to improve system wide sustainable behavior (Loorbach, van Bakel, Whiteman, & Rotmans, 2010). On the other hand, incumbents can have an enabling role in fostering niche innovations (Ampe, Paredis, Asveld, Osseweijer, & Block, 2021; Augenstein & Palzkill, 2016; Berggren, Magnusson, & Sushandoyo, 2015). The role of business in the context of sustainability transitions has been, however, barely explored in literature (Köhler et al., 2019). Accordingly, this thesis focusses on the role of industry (i.e., business) and technology (i.e., SOTs), shown in bold in Figure 1.1.

In the following, in section 1.1.1, the major challenges for business associated with the transfer of emerging SOTs from science to industry are elaborated. Subsequently, a literature review in section 1.1.2 provides an overview of research on the evaluation of emerging technologies in the context of sustainability transitions and thus, reveals the research gaps before developing the research objectives of this dissertation in section 1.1.3.

1.1.1 Challenges associated with the transfer of emerging SOTs

Emerging technologies and especially SOTs often emerge at the interface between science and applied technology (Borge & Bröring, 2020). Before emerging SOTs are tested and further advanced in niche innovations, they need to be assessed by the strategic technology management (Schot & Rip, 1997). However, the evaluation of emerging SOTs and the technology transfer of them are fairly challenging. In this dissertation, technology transfer refers to the economic utilization of scientific findings in industry. Thus, technology transfer is the application of SOTs in industrial scale potentially contributing to a commercialized SOI. There are challenges, such as customer acceptance of the new technology (Christensen, Talukdar, Alton, & Horn, 2011) or missing regulatory frameworks (Morone & D'Amato, 2019) associated with the transfer of emerging SOTs. These challenges are, however, only partially addressed in this dissertation, as they also require a consumer or policy perspective. Accordingly, this thesis addresses three particular challenges for business associated with assessing emerging SOTs and their transfer from science to industry. They are elaborated in the following paragraphs.

Challenge 1- high unfamiliarity and missing know-how of incumbents

SOTs often emerge from interdisciplinary research (Borge, Wustmans, & Bröring, 2022). For example, SOTs, such as resource recovery or bio-based technologies, are unfamiliar business fields for traditionally fossil-based industries, such as the chemical industry (Carraresi & Bröring, 2021). Another example are digital technologies, such as artificial intelligence (AI) or Internet of Things (IoT), which, if properly applied, are also considered as SOTs as they can also contribute to sustainability transition (Bohnsack, Bidmon, & Pinkse, 2022; Di Vaio, Boccia, Landriani, & Palladino, 2020; Gupta, Motlagh, & Rhyner, 2020). In this context, for incumbent firms it is challenging to balance the exploitation of existing capabilities developed in the past and new digital capabilities required to implement digital innovations (Svahn, Mathiassen, & Lindgren, 2017).

Another barrier for an emerging SOT to diffuse into the market is that an incumbent technology usually has a larger accumulated knowledge base within companies. Furthermore, it depends on the degree of innovativeness (i.e., incremental vs. radical) how easy companies can adapt to a new SOT (Hötte, 2021). In addition, the information on emerging business fields is not identified by corporates that are focused on the current business (Heger & Rohrbeck, 2012). Eventually, the strategic management of companies needs different types of information to make decisions (Heger & Rohrbeck, 2012; Wustmans, 2019).

Challenge 2 – high uncertainty

Emerging technologies are generally characterized by high uncertainty (Rotolo, Hicks, & Martin, 2015). There are two types of uncertainty in emerging technology projects (Tiwana, 2014). First, technological uncertainty resulting from immature technologies, complexity and the need for integrating with existing technologies (Berg, Wustmans, & Bröring, 2019; Tiwana, 2014) and second, market uncertainty associated with the challenge of predicting an emerging technology's future market appeal and the ambiguity about the timing of necessary complementary downstream products and services (Tiwana, 2014). For instance, emerging SOTs such as biorefinery converting biomass into viable products do not only require the feedstock, i.e., biomass, but also innovations originating from various other fields, such as bioengineering, polymer chemistry, food science or agriculture (Ohara, 2003). The same applies to markets driven by emerging digital platform technologies, where the platform owner (i.e., owner of the platform technology and the core product) relies for example on app developers or complementary suppliers (Tiwana, 2014).

Emerging SOTs represent a complex system, as those technologies for instance have to integrate in existing structures, compete with former technologies and need to respond to rapidly changing environments as well as changing user and business requirements (Akoka & Comyn-Wattiau, 2017; Geels & Schot, 2007). In contrast, Rotolo et al. (2015) claim that the analysis of emerging technologies does not necessarily require the understanding of the origin and the causal relationships of the entire system. They argue that emerging technologies are rather about "[…] identification at an early stage, and visibility and prominence" (Rotolo et al., 2015). This might be true with respect to the identification of emerging technologies. However, being confronted by the decision to implement a new technology it is not only the technology itself, which evokes uncertainty. Also, the uncertainty about the relationship between the technology and its technological infrastructure, from which it emerges as well as the uncertainty about alternative technologies are important factors to be considered (Meijer, Hekkert, Faber, & Smits, 2006).

Challenge 3 – systemic complexity and transformation of existing industries

Sustainability transition is not restricted to a single technology or a single company, but rather involves a wider ecosystem (Adams, Jeanrenaud, Bessant, Denyer, & Overy, 2016). It requires the collaboration with other actors in the innovation ecosystem to successfully implement complex innovative technologies (Planko, Chappin, Cramer, & Hekkert, 2019). However, incumbents present a hurdle in implementing SOTs, as it is claimed that many incumbents try to protect their old business and stick to proven strategies and business models (Augenstein & Palzkill, 2016). Although, it is important to look beyond single organizations, and to also take their embeddedness into value chains or stakeholder networks into account (Aagaard, Lüdeke-Freund, & Wells, 2021). Similarly, it is important to look beyond regimes and systems, as different regimes may influence niche-innovations and vice versa (Ampe et al., 2021).

Many SOTs reveal cross-sectional characteristics, which makes it difficult to integrate SOTs into existing systems (Kemp et al., 1998). For companies it is more difficult to deal with systemic innovations than with purely incremental or radical innovations. The latter can be handled with existing organizational structures. Systemic innovations, on the contrary, require accessing a company's current skills and resources while simultaneously reshaping them into a new system (Henderson, 2021). The success of a systemic innovation depends on the involvement of different actors and complementary innovations from the entire industry (Bohnsack, Kolk, Pinkse, & Bidmon, 2020; Bröring, 2008; Teece, 2002).

1.1.2 Research gaps

Considering on the one hand that emerging SOTs and their individual selection and evaluation are crucial for a sustainability transition of current less sustainable systems (Markard et al., 2012) and on the other hand that companies seek to assess the impact of individual technologies or technology fields on the company's future competitiveness in existing and emerging markets (Schimpf & Rummel, 2015), this thesis investigates the extant literature. Accordingly, an extensive literature review is conducted to elucidate how emerging technologies in the context of sustainability are evaluated from a business perspective. To this end, the WebOfScience^{TM} database of Clarivate Analytics is used to provide an overview of existing empirical studies. The following keyword search string was used:

> *Topic = ((Assess* OR identif* OR evaluat* OR select* OR "market penetration*" OR diffus* OR commercializ* OR "technology transfer") AND ((emerging* NEAR/5 technolog*) OR "emergence of technolog*") AND sustainab* AND (compan* OR business* OR organization* OR firm* OR practitioner* OR manager*))*
> *Year=1945-01-01 to 2021-12-31*

The application of the search string resulted in a total of 215 publications. After title and abstract screening for studies focusing on the identification or evaluation of emerging technologies in the context of sustainability, 55 studies were identified as relevant to provide an overview of this thesis' research focus. Table A1 in the appendix of this thesis provides a holistic overview of the results of the literature review. Most publications (*N*=13) conducted literature reviews to identify and assess various emerging SOTs, such as for example treatment technologies for saline wastewater (Marathe, Singh, Raghunathan, Thawale, & Kumari, 2021) or smart manufacturing (Kerin & Pham, 2020). Another main stream of research on the assessment of emerging SOTs from a technology perspective is dominated by applying environmental accounting tools, such as life cycle assessment (LCA) (e.g. Tsalidis & Korevaar, 2022) or quantitative assessment of energy and water savings (e.g. Gao, Na, Song, Tian, Strawa, & Du, 2020) (in total *N*=14). Another stream of research applies methods for strategic technology management mainly based on patent data (e.g., Nordensvard, Zhou, & Zhang, 2018) (*N=6*). The already published study by Block, Wustmans, Laibach, and Bröring (2021) being part of this dissertation also belongs to this group of papers. Some publications address the societal impacts of emerging SOTs, for instance, by examining the perception of various stakeholders toward an emerging SOT to promote its market application (e.g. Schaeffer, Schaeffer, Keith, Lunetta, Conmy, & Gould, 2013) (*N*=3). In addition, a few publications connect the emergence of new technologies with the evolution of new (sustainable) business models to successfully commercialize emerging SOTs (e.g. Reinhardt, Christodoulou, Gassó-Domingo, & Amante García, 2019) (*N*=2). The remaining 17 publications cannot be subsumed under a common research approach, as they individually address unique research problems in the context of emerging SOTs. They cover for example, the assessment of a technology's acceptability (Ryan, Antoniou, Brooks, Jiya, Macnish, & Stahl, 2020), the willingness to pay (Zhang, Song, Yang, & Li, 2020) or the role of policy (Hung & Chu, 2006). The screening of the publications revealed that they, first, have different foci on the way from early technology forecasting towards the evaluation of more mature or already implemented technologies and second, take different perspectives on technology assessment.

Accordingly, in order to provide a simpler overview of the existing literature and the identified research gaps, Figure 1.2 offers a visual representation of the relevant publications, which are sorted within a matrix. The x-axis of the matrix shows the study's focus of technology evaluation from ex-ante before an emerging technology's commercialization until ex-post characterized by a specific focus on technologies being either already implemented in the market or being adopted by market actors. That means, papers on the left-hand side of the matrix apply technology forecasting, papers in the middle combine technology forecasting with the comparison of already implemented technologies or the inclusion of factors for a technology's market adoption and papers on the right hand-side focus on the evaluation of implemented technologies or technologies with high commercial exploitation potential. The y-axis clusters the results into three different perspectives, namely technology, company/expert and ecosystem pointing to the scope of research. That means, papers sorted to the technology perspective take a technology into the center of analysis. Papers sorted to the company/expert perspective incorporate the opinion or perception of relevant experts (e.g., researchers in the field) or companies to evaluate the technology. Eventually, papers sorted to the ecosystem perspective consider different angles and take a holistic view on the evaluation of emerging technologies.

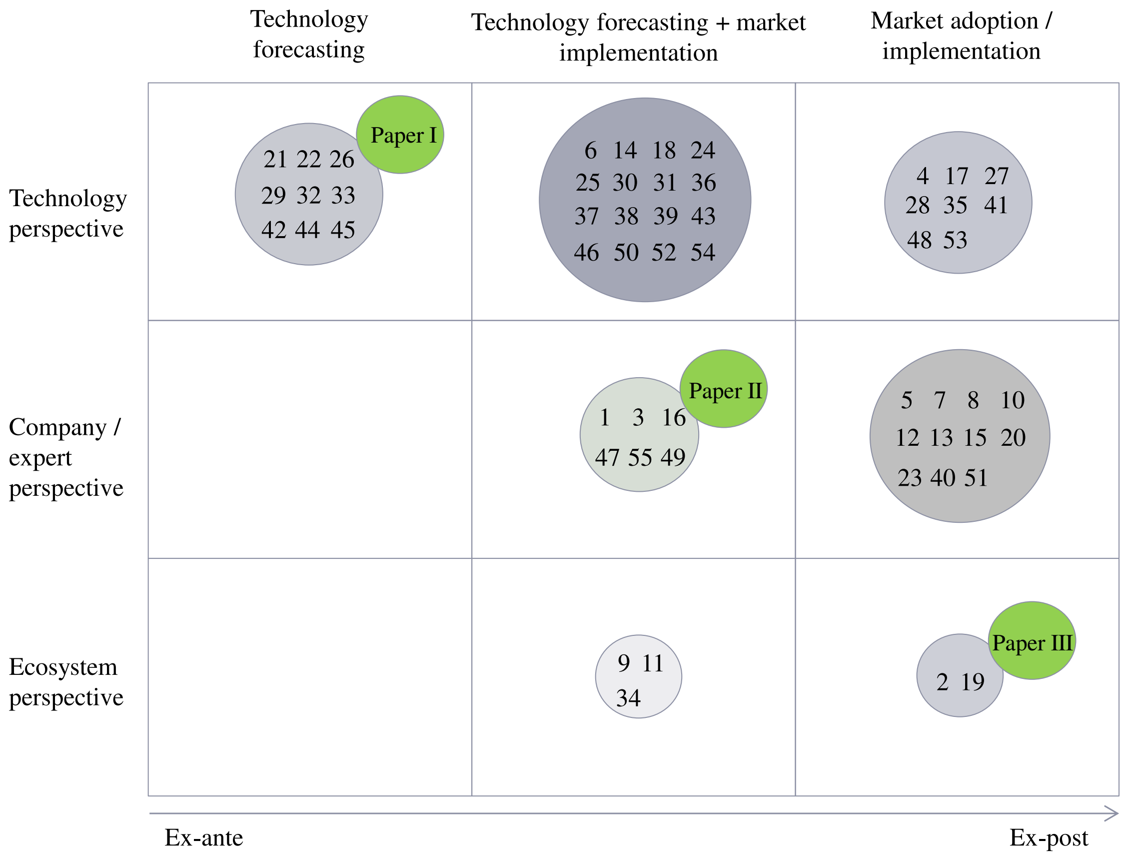

Figure 1.2: Result of the literature review and elaboration of the existing research gaps.

Remark: Each number in Figure 1.2 represents an individual paper included in the literature review. A legend of the numbers and the respective publications is provided in the appendix in Table A2. The green circles represent the three studies conducted as part of this dissertation. It should be noted that publication number 45 is equal to paper I conducted within this dissertation.

Based on some examples taken from the matrix, the research gaps and positioning of the dissertation are illustrated in the following. From a technology perspective, publications sorted to technology forecasting conduct for instance ex-ante LCA [26] (Tsoy, Steubing, van der Giesen, & Guinée, 2020), literature review to identify emerging technologies [33] (Lu, Tam, Chen, & Du, 2020) or science mapping analysis [42] (Yevu, Yu, & Darko, 2021). Publications sorted in the middle combining or comparing technology forecasting with implemented technologies can be, hence, understood as studies focusing on the transition between technology forecasting towards technology transfer. For example, papers sorted to this area compare results of ex-ante and ex-post LCAs [24] (Tsalidis & Korevaar, 2022) or develop a predictive model for technology transfer [52] (Choi, Jang, Jun, & Park, 2015). Eventually, papers sorted to the consideration of market implementation from a technology perspective conduct environmental impact assessment of an already implemented technology [17] (Liu, Agusdinata, & Myint, 2019) or conduct literature review to evaluate the functionality of implemented technologies [53] (Chen et al., 2022).

From company perspective, papers sorted in the middle, for instance, analyze managers' individual motives and visions related to an emerging technology [16] (Krätzig, Franzkowiak, & Sick, 2019) or assess opportunities, risks and challenges associated with an emerging technology based upon interviews with managers. Papers considering the market implementation take business model innovations [15] (Olleros, 2017) and decision-making models for companies [12] (Lizarralde, Ganzarain, & Zubizarreta, 2020) into account.

From ecosystem perspective, there are a few papers in the middle considering for example, knowledge flows between firms to identify innovation core and innovations periphery countries [11] (Nordensvard et al., 2018) or apply actor-network analysis [9] (Farhangi, Turvani, van der Valk, & Carsjens, 2020). Two papers were sorted to ex-post evaluation of emerging technologies exploring the role of digital inter-organizational knowledge networks [19] (Csedő, Zavarkó, Vaszkun, & Koczkás, 2021) or applying the technology innovation system (TIS) approach to identify and analyze factors that enable successful innovation [2] (Andersson, Hellsmark, & Sandén, 2018). From company and ecosystem perspective, there are no papers in the literature review that address early ex-ante technology forecasting. A reason might be that initially the technology is the center of analysis before stakeholders, such as companies or entire ecosystems, requiring a certain technology maturity, can be included in the assessment. Within the wider research landscape, there are indeed studies that also cover these early phases from an ecosystem perspective, but they do not focus on emerging technologies, but rather on different roles in emerging innovations ecosystems (e.g., Dedehayir, Mäkinen, & Roland Ortt, 2018).

From the literature review it can be learned that in order to achieve a technology transfer of emerging SOTs from science to industry (i.e., business) different perspectives on technology assessment need to be considered. Accordingly, this thesis identifies three major research gaps. First, it can be concluded that most studies use a technology perspective to assess emerging technologies in the context of sustainability (*N*=33). However, only nine of them focus on early technology forecasting and a few studies (*N*=6) identify and evaluate emerging technologies from a strategic technology management perspective. Thus, the closer inspection of the literature reveals that there are not many publications providing an early assessment of emerging technologies in form of a forecasting tool. However, the identification of relevant emerging technologies is pivotal for managers, researchers and policy makers, as these actors need to anticipate the future development and impact of emerging technologies in order to evaluate business opportunities and set strategic priorities (Rotolo et al., 2015). Another challenge, being particularly evident in the highly interdisciplinary field of SOTs (Borge et al., 2022; Borge & Bröring, 2017; Carraresi et al., 2018; MacLeod, 2018), is that new knowledge is often generated primarily in special communities, but the knowledge itself has to be applied by actors, who are usually not familiar with the knowledge field (Porter & Cunningham, 2005). Especially in highly dynamic environments, such as sustainability transitions, technological foresight is essential to facilitate the understanding and anticipation of technological changes (Reger, 2001). Hence, a forecasting method is needed, which offers a comprehensive overview of the existing research and technology fields to provide objective evaluation criteria. There are a few studies conducting either publication or patent analysis, but a combination of both data sources is missing. This is the focus of the first paper within this dissertation, which is at the same time paper number [45] within the literature review.

Second, there are several papers taking a company perspective. However, the incorporation of the systemic complexity of many SOTs on the way from technology forecasting toward market implementation is missing, although, as elaborated in the previous chapter, the systemicness of many emerging SOTs present a major hurdle in applying them on market scale. Literature provides insight into tools and methods for technology selection and evaluation being applicable in companies (Heslop, McGregor, & Griffith, 2001; Schimpf & Rummel, 2015). However, they, first, miss the particular context of sustainability transition and second, do not consider technology evaluation from company perspective along different value chains.

Third, the ecosystem perspective is barely explored as well. Technologies not only have to be implemented within companies but also on ecosystem level. The implementation of these technologies is often accompanied by systemic changes along value chains or entire business ecosystems. Also, companies seek to create and capture value when commercializing new technologies being embedded in a business ecosystem comprising heterogenous stakeholders, technologies and regulations (Demil, Lecocq, & Warnier, 2018). That requires a balance between cooperation and competition among actors within the emerging business ecosystem. Hence, actors may follow different strategies to position themselves and to establish bargaining power vis-a-vis other actors in the emerging business ecosystem (Hannah & Eisenhardt, 2018). The evaluation of (new) business strategies when implementing emerging SOTs considering the competitive business ecosystem is fairly neglected so far.

This literature review provides an initial overview of the domain of assessing emerging technologies in the field of sustainability from a business perspective. The individual studies (see *chapters 2* to *4*) within this dissertation provide narrower insight into the respective current state of literature.

1.1.3 Research objectives

Business plays an important role in achieving sustainability transition. It may also take a proactive role. In section 1.1.1, the major challenges for companies, such as high unfamiliarity, high uncertainty and the systemicness of emerging SOTs have been elaborated. This thesis seeks to address these challenges to achieve the main goal *to foster the transfer of emerging SOTs from science to industry to eventually contribute to the transition of current business towards greater ecological sustainability.*

To achieve the main goal, this thesis follows two objectives:

I. To derive criteria for the evaluation of emerging SOTs from business perspective
II. To derive strategies how companies can position in an emerging business ecosystem driven by new technologies

This thesis is aiming to support the strategic evaluation and commercialization of SOTs towards a transition of a more sustainable economy. The results should provide guidance for managers looking for patterns and guidance in achieving sustainable transitions on the one hand and reveal strategies in positioning in emerging business ecosystems on the other hand. It is doing so by addressing the research gaps elucidated in the previous chapter. First, it seeks to advance methodologies to early assess emerging SOTs *(chapter 2)*. Second, it aims at identifying and rating criteria that are relevant for companies along value chains when evaluating SOTs *(chapter 3)*. Third, it seeks to identify and evaluate positions in an emerging business ecosystem where potentially high value can be created and captured through the emergence of technologies *(chapter 4)*.

1.2 Theoretical background

The objectives of this dissertations have a strong industry and application focus, which relies on the theoretical background of emerging technologies and business ecosystems. This chapter provides, first, a profound understanding of emerging technologies and emerging SOTs in particular. Subsequently, it introduces the concept of emerging business ecosystems.

1.2.1 Emerging sustainability-oriented technologies

Technology appears either in its disembodied form (e.g., scientific results) or in form of new products (e.g., advances in design and quality of new products) (OECD, 2001). Technology is often associated with science and engineering and can be considered as a certain type of knowledge that is applied by for instance companies (Phaal, Farrukh, & Probert, 2004). In contrast to innovation which incorporates the step of commercialization, technology can be considered as an enabler, consisting of theoretical and practical knowledge that can be used to develop products and services (Burgelman, Christensen, & Wheelwright, 2009; Nieto, 2003). In comparison to mature technologies, which are characterized as more stable and predictable, Rotolo et al. (2015) claim that emerging technologies fulfill five criteria, namely radical novelty, relatively fast growth, coherence, prominent impact and uncertainty and ambiguity. In addition to this understanding, using philosophy of science, complexity theory, and evolutionary economics, Burmaoglu et al. (2019) defines technology emergence as a cyclic process in highly creative scientific networks that shows qualitative novelty, qualitative synergy, irregular trend, high functionality, and continuity, emphasizing the importance of qualitative aspects from a microstate, i.e., individual technology, perspective. However, emerging technologies reveal their individual characteristics with respect to different socio-technical features such as e.g., involved actors, technical difficulties or applications (Rotolo et al., 2015).

Policymakers or business strategists have incomplete knowledge when it comes to predicting the boundaries and the direction an emerging technology is moving (Rotolo, Rafols, Hopkins, & Leydesdorff, 2017). Especially, emerging technologies which are science-based innovations and have the potential to disrupt current industries, pose a particular challenge for strategic management (Cozzens et al., 2010; Day & Schoemaker, 2000). Emerging technologies require a change in status quo capabilities and a focus on early warning indicators, as many emerging technologies have long development times (Burmaoglu et al., 2019). Accordingly, firms apply different innovation and technology policies to keep pace with emerging technological changes and to remain competitive (Porter, 2007).

According to Day and Schoemaker (2000) emerging technologies have “the potential to create a new industry or transform an existing one”. They include radical innovations or the emergence of technologies from the convergence of originally different research streams. Porter, Roessner, Jin, and Newman (2002) refer to emerging technologies as technologies which have the potential to exert great economic influence in the coming 15 year horizon. Cozzens et al.'s (2010) definition of an emerging technology points to its high potential, which has not been demonstrated by value creation so far.

Research on emerging technologies gained considerable attention in various fields, such as biotechnology, information technology or nanotechnology (Li, Porter, & Suominen, 2018). Strategies, such as the European Green Deal or the United Nations’ Sustainable Development Goals (SDGs) also support the emergence of SOTs from a regulatory-push perspective (Arash, Samira, & Arho, 2020; Horbach, 2008). Many SOTs are incremental. However, to make progress and achieve radical changes in the current systems, systemic technological innovations are required. The sustainability transition of the energy or transport sector, for example, requires new sourcing of materials or new infrastructures and hence, a new configuration of the social and technical infrastructure (Henderson, 2021). Thus, from a network or ecosystem perspective, technology does not work in isolation but needs to be compatible with other products or systems (Kim, 2003).

Many SOTs are still in the laboratory phase since academia and industry actors are uncertain about future market potential. Applied to the case of the sustainability transition of the fossil-based toward the bio-based economy, this implies that companies are conservative in substituting established technologies by new bio-based processes. Emerging technologies go along with the questions how they may deliver new features to satisfy customer needs and how they can compete with established technologies in terms of costs (Day & Schoemaker, 2000). For example, technologies for resource recovery have to compete with traditional fossil extraction. Moreover, strategic technology management faces the challenge to identify the relevant technologies in order to assess their future potential, since those technologies have to be applied by industries, which were previously not in touch with the issued described above.

Companies need to be aware of new trends in their original industry but also outside their own industry. In addition, they have to combine signals coming from outside with their own internal strategy (Battistella & De Toni, 2011). With respect to the transition from fossil-based towards a bio-based economy, this might pose a great challenge to established industries, such as agriculture or food industry, as they would enter completely new markets, if they for instance recover resources which in turn can be used in different industry sectors. According to Day and

Schoemaker (2000), the organization requires a learning capacity to be able to absorb the information from the periphery. That implies that companies need to be open to different viewpoints within and across organizational units, they need to be willed to challenge their originals assumptions and they have to be open for an iterative approach for the experimentation of a new process (Day & Schoemaker, 2000). Therefore, the individual interactions of stakeholders, employees or managers is an essential leverage for the implementation of a new technology.

1.2.2 Emerging business ecosystems

The notion of ecosystems was introduced into the management literature by Moore (1993) to understand the context within which business competes and collaborates. A business ecosystem is often characterized by spanning traditional industry boundaries to offer a common value proposition (Adner, 2017; Yoo, Boland, Lyytinen, & Majchrzak, 2012). Research on ecosystems shows that managers and academia require new strategic thinking and tools to make successful decisions and recommendations (Stonig & Müller-Stewens, 2019). Business ecosystems often emerge from technology or industry convergence (Aaldering, Leker, & Song, 2018), which can be observed in various industries, such as at the interface between the food, pharmaceutical and chemical industry in the area of functional foods (Block, Berg, Wustmans, & Bröring, 2018), at the interface between the agricultural, chemical and consumer industries whose boundaries are blurring by moving from a fossil-based towards a bio-based economy (Boehle & Bröring, 2011) or at the interface between the bio-based economy and the digital economy (Rennings, Burgsmüller, & Bröring, 2022). In Waßenhoven, Block, Wustmans, and Bröring (2020), we could show that the bio-based economy can be considered as an emerging highly interdisciplinary business ecosystem. Accordingly, nowadays a company's performance and value creation increasingly rely on actors outside the traditional value chain, which is moving towards business ecosystems (Iansiti & Levien, 2004). Linear value chains are replaced by value networks and business ecosystems. In contrast to the value chain, ecosystems rely on horizontal interaction (Stonig & Müller-Stewens, 2019), where corporation and competition play a central role (Hannah & Eisenhardt, 2018).

1.3 Research questions

According to the first objective, namely to derive criteria for the evaluation of emerging SOTs from business perspective (cf. section 1.1.3), this thesis aims to answer three research questions (RQ) that are elaborated in section 1.3.1 and 1.3.2. To achieve the second objective, namely to derive strategies how companies can position in an emerging business ecosystem driven by new technologies, section 1.3.3 derives RQ 4.

1.3.1 Assessing emerging technologies from a technology perspective

Stakeholders, such as policymakers or business strategists have incomplete knowledge when assessing the boundaries and direction in which an emerging technology is developing (Rotolo et al., 2017). Since emerging technologies are often science-based innovations and have the potential to disrupt current industries, they pose particular challenges for strategic management (Cozzens et al., 2010; Day & Schoemaker, 2000). However, the literature review in section 1.1.2 suggests that an objective forecasting tool for emerging SOTs is missing. As bibliometric approaches play one of the essential roles in order to identify how and which new technologies emerge (Bildosola, Gonzalez, & Moral, 2017), the first RQ of this thesis is as follows:

RQ 1: How can sustainability-oriented technologies be identified and evaluated by means of secondary data sources?

1.3.2 Assessing emerging technologies from a company perspective

Beside institutions or society, companies play a crucial role in sustainability transitions (Bähr & Fliaster, 2022; Köhler et al., 2019). Literature would benefit from an exploration of how different industry sectors along a value chain evaluate SOTs from their individual company perspective. This is especially needed since the character of many SOTs can be classified as systemic and industry boundary spanning (Bohnsack et al., 2020; Bröring et al., 2020), which hence require coordination across different partners to ensure resource complementarity and interfaces. Thus, for business to reach a sustainability transition, it seems pivotal for the implementation of SOTs to understand and consider selection criteria from different stakeholders along the value chain.

Such a systemic perspective on SOT evaluation is so far lacking in the literature (see chapter 1.1.2). It is barely explored how different industry stakeholders, i.e., industries along a value chain, evaluate the relevancy of different evaluation criteria. A context, where value chains and the individual perception of different stakeholders towards the emergence of SOTs play a crucial role is the bio-based economy. Here, the socio-technical regime of a fossil-based economy is heading towards an economy built upon bio-based and renewable resources (Dietz, Börner, Förster, & Braun, 2022; Geels & Schot, 2007; Vandermeulen et al., 2012). Therefore, applied to the case of the bio-based economy, the second and third research questions are as follows:

RQ 2: What are the criteria for selecting a sustainability-oriented technology from a value chain spanning perspective in the case of the bio-based economy?

RQ 3: How do the perceptions of relevancy of these criteria differ between stakeholders along value chains of the bio-based economy?

1.3.3 Assessing emerging technologies from an ecosystem perspective

The literature review in section 1.1.2 has also shown that the ecosystem perspective tends to be neglected in the context of emerging technology assessment. One sector where we can observe the phenomenon of nascent business ecosystems through emerging SOTs is the agricultural industry (Van Dyck, Lüttgens, Piller, & Diener, 2021). Here, SOTs, such as smart or precision farming technologies are playing an increasing role in sustainable land management and the networking of different systems (Dörr & Nachtmann, 2022). Incumbent companies face the challenge of positioning themselves in the emerging data-driven system, where the integration of intelligent agricultural technology (e.g., sensors) and modern data technology (e.g., AI) enable high productivity in crop cultivation while securing sustainability.

Both sustainability and digitalization are often strategic drivers for new business or the change of existing products (Kennedy, Whiteman, & van den Ende, 2017; Lee & Berente, 2012; Teece, 2018). If properly applied, digital technologies can enhance firms' environmental performance (Bonilla, Silva, Terra da Silva, Franco Gonçalves, & Sacomano, 2018). For instance, digital platforms may contribute to sustainability transitions as they might obtain substantial power to influence multiple actors' behavior and patterns of sustainability transitions (Kolk & Ciulli, 2020).

Although both trends are converging while tackling grand challenges, such as climate change or environmental degradation, digitalization and sustainability are mostly analyzed separately in strategic management literature (George, Merrill, & Schillebeeckx, 2020). This thesis seeks to address this research gap while examining the business ecosystem strategies of actors in an area where sustainability and digitalization are converging. Eventually, in order to achieve objective II of this dissertation to derive strategies how companies can position in an emerging business ecosystems driven by new technologies, the fourth research question is as follows:

RQ4: How do companies position themselves to achieve bargaining (market) power and a competitive advantage in an emerging digital business ecosystem?

1.4 Research design and structure of the thesis

This thesis is structured into five chapters. Figure 1.2 provides an overview of how the studies (chapters) are related to each other and how they contribute to the objectives and research questions elaborated in the previous sections. Further, Table 1.2 shows the details of the empirical studies. Those illustrations present the five chapters of this thesis, which are shortly introduced in the following: *Chapter 1* introduces the motivation and research background of emerging technologies and their potential to disrupt industries as well as companies' role in fostering the transition towards a more sustainable economy. It elaborates on the theoretical background and points out which research gaps this thesis is seeking to close. In this thesis, three empirical studies based upon primary and secondary data sources are conducted. *Chapter 2* to *4* encompass these empirical studies.

Accordingly, *chapter 2* entails the first study of this dissertation and elaborates a methodology to bridge scientific knowledge reflected in publications with technological knowledge reflected in patent data to provide an evaluation tool for SOTs. The study, hence, assesses emerging technologies from a technology perspective. Applied to the highly dynamic case of phosphorous recovery as an emerging SOT field, this chapter proposes a semantic similarity analysis approach of patent and publication documents following suggestions by Niemann, Moehrle, and Frischkorn (2017). Mapping the timely development of emerging sub-technologies in the domain of phosphorous recovery and the new developed indicator, the number of semantically similar publications per patent belonging to a specific sub-technology, contribute to the identification and evaluation of emerging technologies in the highly dynamic context of sustainability transitions. We can use secondary data sources to identify and evaluate SOTs itself. However, the technology transfer and their market implementation are eventually driven by different stakeholder perceptions and expectations. In addition, a major hurdle in implementing SOTs is often the need to change existing systems and value chains (Carraresi et al., 2018).

As a consequence, *chapter 3* seeks to identify selection and evaluation criteria for emerging SOTs from a company perspective along a value chain. For this purpose, a Group Concept Mapping (GCM) study, which is a mixed-method approach aiming at the integration of input from multiple stakeholders with different interests and expertise from a bottom-up perspective, has been conducted (Trochim, 1989). It enables the presentation of concept maps that visualize the collective thinking of a group in relation to the research problem under consideration – in this case the selection criteria for SOTs from a company perspective. These maps can be used as a guide for action planning or program evaluation to foster the implementation of emerging technologies striving for sustainability transition. Applied to the case of the bio-based economy, this study seeks to aggregate the perceptions of four different stakeholder groups (in total 49 actors) along the value chain, i.e., (1) agricultural and feedstock, (2) (bio)-chemical, (3) consumer industries and (4) consultancies and networks. The study derives 11 different categories that have been perceived as relevant when selecting SOTs. Following from the systemic character of many SOTs, not only value chains but entire ecosystems need to jointly create value to achieve sustainability transitions and an economic added value.

Accordingly, *chapter 4* takes an ecosystem perspective and analyses how companies can position in a business ecosystem arising through the emergence of new technologies – more specifically digital technologies, such as precision farming technologies, which may contribute to a sustainability transition (Miranda, Ponce, Molina, & Wright, 2019). This chapter relies on a qualitative case study design. The particularity of qualitative case studies is that the focus is on explaining and analyzing the context of a phenomenon and its influences (Yin, 2009). Thus, in case study research the investigator explores current, real-life cases that can be bounded within certain parameters while collecting in-depth data involving multiple sources of information (e.g., interviews, documents or reports) (Creswell, 2013). More precisely, chapter 4 of this thesis applies a multiple-case study design seeking to gain multiple perspectives on the impact of digital technologies on the business ecosystem of the agricultural industry through semi-structured interviews with 15 companies, industry associations and consultancies and additional secondary data, such as websites and business reports. Chapter 4 sheds light on the concept of control points reflecting the dynamic bargaining situation in emerging digital business ecosystems. The chapter shows the evolution of control point portfolios over time and derives control point strategies how companies position themselves to react to threats, such as technological or institutional change.

Eventually, *chapter 5* summarizes the findings of all three studies and outlines theoretical and methodological contributions of this thesis. It also derives practical implications for managers and policymakers who may drive sustainability transitions along the path from emerging technologies at science and technology level to the commercialization of emerging technology in the marketplace. Finally, the chapter concludes with limitations and potential directions for future research.

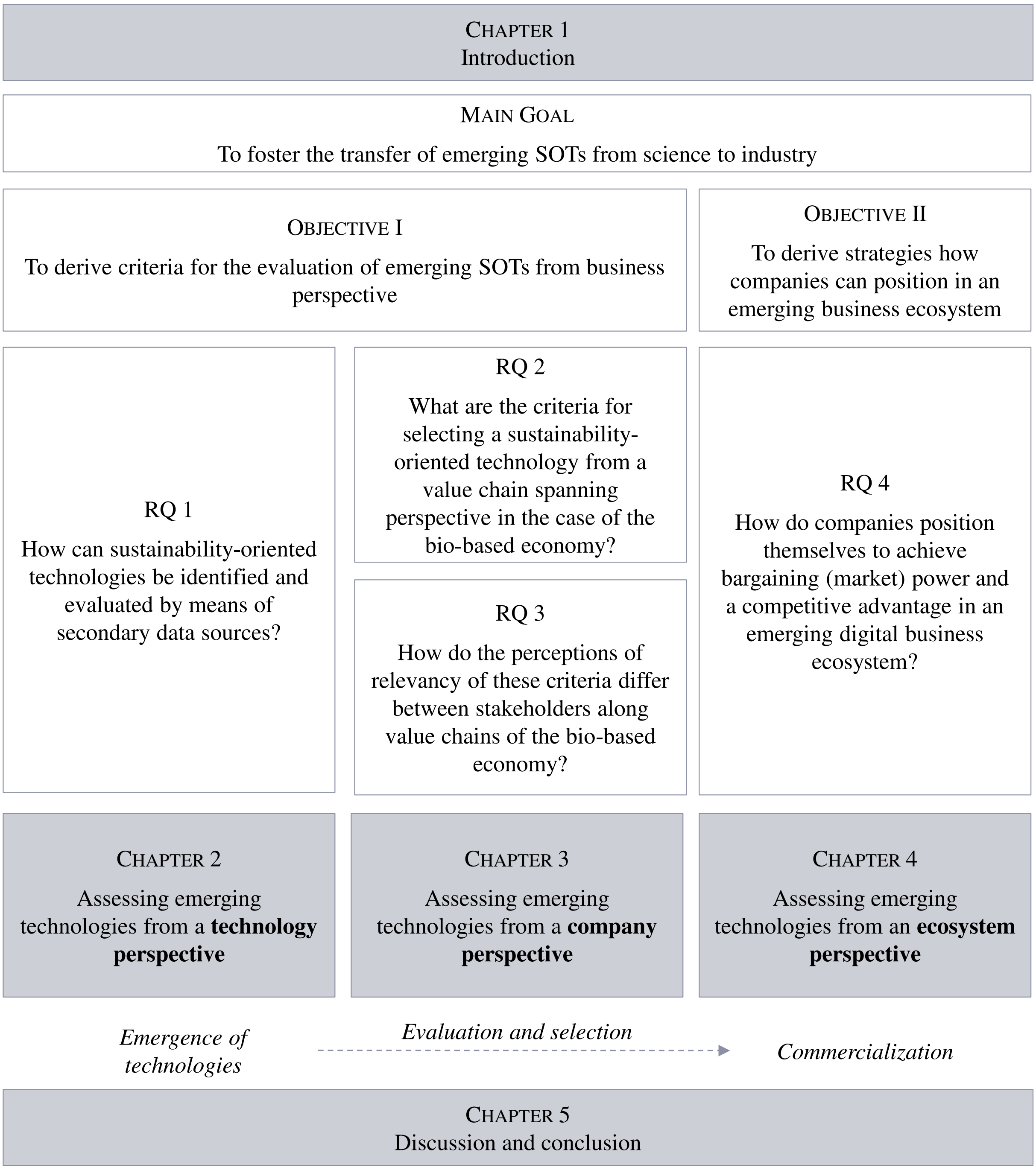

Figure 1.3: Overview of the structure of the thesis.

Table 1.1: Details of the empirical studies within this thesis.

Chapter	Perspective	Unit of analysis	Theoretical background	Research setting	Data set	Main methodological approach	Publication status
2	Technology	Scientific publications and patent documents	Technology foresight of emerging technologies	Phosphorous recovering from wastewater	Patent applications and scientific publications ($N_{patents} = 80$ / $N_{publications} = 386$)	Quantitative approach: Patent and publication analysis (semantic analysis)	Published 2021 in *Technological Forecasting and Social Change* (JIF: 10.884, VHB-JQ3: B)
3	Company	Stakeholders' perception	Sustainability transition and systemic innovation	Value chains of the bio-based economy	Companies, networks and consultancies ($N = 49$)	Mixed qualitative and quantitative approach: Group concept mapping	Published 2022 in *Business Strategy and the Environment* (JIF: 10.801, VHB-JQ3: B)
4	Ecosystem	Companies / business models	Control points within emerging digital business ecosystems	Digital agriculture	Companies and institutions ($N = 15$)	Qualitative approach: Semi-structured expert interviews	To be resubmitted

2 Assessing emerging technologies from a technology perspective

Chapter 2 answers the following research question:

RQ 1: How can sustainability-oriented technologies be identified and evaluated by means of secondary data sources?

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An early version of the paper has been presented at the International Society for Professional Innovation Management (ISPIM) Conference, 16. – 19. June 2019, Florence and at the Summer School for Data & Algorithms on ST&I Studies, 17. September 2020, Leuven.

2.1 Introduction

In the light of current challenges, such as climate change, environmental degradation and resource scarcity, and the associated demands for a transition to a more sustainable economy, sustainability-oriented innovations (SOI) are emerging (Adams et al., 2016; Vandermeulen et al., 2012). SOIs comprise products, processes or services and are characterized by their specific purpose of "creating and realizing social and environmental value in addition to economic returns" (Adams et al., 2016). Evolving concepts such as the circular economy (Stahel, 2016) or the bioeconomy (Golembiewski, Sick, & Bröring, 2015; Staffas, Gustavsson, & McCormick, 2013) underline the potential impact of such SOIs, which all share a high degree of ambiguity and uncertainty. At the same time technological innovation is considered a key driver toward a transition to a more sustainable economy (Hausknost et al., 2017; Philp, 2018; Priefer, Jörissen, & Frör, 2017). In this context, multiple sustainability-oriented technologies (SOTs) are emerging (Mayer et al., 2016; Stahel, 2016). They have no dominant design yet and have to compete with prevailing less sustainable technologies (Alkemade & Suurs, 2012; Berg et al., 2019; Suárez & Utterback, 1995). Especially for SOTs, which may for instance contribute to the transition towards a more sustainable direction in terms of resource usage, challenges such as high uncertainty, high investments and late returns impede the evaluation of their impact and their future development (Alkemade & Suurs, 2012; Kemp & Soete, 1992), which is even more challenging within the highly ambiguous early phase of emergence (Rotolo et al., 2017).

Emerging technologies have the potential to create new industries, transform existing ones or cannibalize present business models (Day & Schoemaker, 2000). However, such a systemic change to a more sustainable, circularity-oriented economy is only possible, if new potential technologies diffuse from scientific knowledge into marketable processes (Geels & Schot, 2007; Vandermeulen et al., 2012). Thus, the identification of relevant emerging technologies is pivotal for innovation managers, researchers and policy makers, as these actors need to anticipate the future development and impact of emerging technologies in order to evaluate business opportunities and set strategic priorities (Rotolo et al., 2015).

In this regard, Rotolo et al. (2015) provide an overview of five main categories for operationalising emerging technologies, namely indicators and trend analysis, citation analysis, co-word analysis, overlay mapping, and hybrid approaches. Within the five main categories, various data sources can be used for the assessment of emerging technologies, such as scientific literature or patent data (Daim, Rueda, Martin, & Gerdsri, 2006; Kwon, Liu, Porter, & Youtie, 2019). In this regard, patents describe the technology and publications may provide the scientific background of emerging technologies (Ávila-Robinson & Sengoku, 2017). Being confronted with the challenge to detect and evaluate different emerging technologies with a similar purpose, the concurrent analysis of patent and publication data can support decision makers to identify the relevant body of knowledge (Kwon et al., 2019). The majority of literature uses citation network analysis to identify trends and growth in specific research or technology areas or the mutual influence of different research topics (Goeldner, Herstatt, & Tietze, 2015; Ho, Saw, Lu, & Liu, 2014; Kajikawa & Takeda, 2008; Kajikawa, Yoshikawa, Takeda, & Matsushima, 2008). However, the bridging of both data sources with respect to a particular technology cluster presents a challenge, as for instance time lags between cross-citations complicate the evaluation of connectivity (Passing & Moehrle, 2015). To identify emerging technologies, both patent and publication data need to be considered simultaneously despite the time lag as some important developments may be published but not patented and vice versa (Ogawa & Kajikawa, 2015). Previous literature in the domain of technological forecasting, which has introduced approaches to bridge these data sources, is mostly focusing on the actor level in terms of authors or assignees (van Looy, Debackere, Callaert, Tijssen, & van Leeuwen, 2006), instead of operationalizing a technology-based approach. Especially in the highly interdisciplinary field of SOTs (Borge & Bröring, 2017; MacLeod, 2018), which emerges at the interface between science and technology, a forecasting method is needed, which offers a comprehensive overview of the existing research and technology fields and thus allows to bridge different data sources.

Therefore, by adopting a holistic perspective we aim at simultaneously looking at knowledge from scientific publications (mirroring scientific research) and patents (reflecting technology fields) to understand the underlying dynamics of emerging technologies in a context of sustainable transitions. To be more precise, this paper seeks to directly link scientific and technological knowledge based upon semantic similarity analysis to obtain a nuanced measure to identify emerging technologies and thus contributing to technological forecasting. The immense growth in publication and patent data led to the emergence of different text mining techniques (Kim, Han, Lee, Cho, & Lee, 2019; Porter & Cunningham, 2005). Joining these methodological advancements, we will base our approach on semantic similarity analysis to propose a new indicator reflecting the number of scientific publications per patent document so as to estimate the relevance of the identified emerging technology.

For our analyses, we assess emerging SOTs drawn from the developing and highly dynamic field of phosphorous recovery. More specifically, to recover phosphorus from wastewater – currently, amongst others the most prominent resource for recycling phosphorus (Egle, Rechberger, & Zessner, 2015). Phosphorus is an essential resource to, e.g., boost growth of agricultural products, to stabilize food products or to improve washing performance (Schipper, 2016). The element phosphorus is still predominately mined from finite phosphate rock and its excessive use is responsible for severe environmental pollution (Steffen et al., 2015). Thus, novel SOTs are needed to allow for the emergence of novel value chains and a more sustainable phosphate cycle.

The remainder of this paper is structured as follows: First we give a short overview of the theoretical background of technological foresight of emerging technologies and different approaches for assessing the emergence of technologies in section 2, which leads to the argumentation of why the combination of publication and patent data is a valuable source for detecting emerging technologies. Subsequently, the methodology part in section 3 firstly introduces the case study of phosphorous recovery as an emerging SOT and thereafter describes the methodological framework along with the data generation process. Section 4 presents the identified emerging technologies based upon patent data over the course of time and the semantic alignment of respective publications. Additionally, therein we remark what this could implicate for the assessment of an emerging technology as well as the bridging of different data sources. Section 5 concludes with some remarks concerning the implications of our approach for technological forecasting and the assessment of emerging technologies seeking for sustainable transition.

2.2 Theoretical background and literature review

2.2.1 Emerging technologies

In general, emerging technologies can be characterized by five criteria, namely (i) radical novelty, (ii) relatively fast growth, (iii) coherence, (iv) prominent impact and (v) uncertainty and ambiguity (Rotolo et al., 2015). Future changes caused by an emerging technology are hard to predict (Rotolo et al., 2015), since its high potential has not demonstrated its value or has led to any kind of consensus yet (Cozzens et al., 2010).

Usually the prevailing intend of academic research is to explain unknown phenomena and processes instead of producing new commercial products or services (Ogawa & Kajikawa, 2015). In many cases academic research can lead directly to innovation or to the desire to create innovation therefrom. This is, however, often motivated by non-monetary goals, such as sustainability, although this is often challenging (Borge & Bröring, 2020; Ogawa & Kajikawa, 2015). This particularly applies to the emergence of SOT, as publicly financed research projects produce a variety of different technologies striving for resource recovery or the substitution of fossil by renewable resources (Mayer et al., 2016). However, most of the SOTs are still in the laboratory phase and face the challenge in penetrating the mainstream market (Bohnsack et al., 2014; Carraresi et al., 2018), although emerging SOTs might have the potential to create new industries or transform existing ones (in line with Day & Schoemaker, 2000). Accordingly, we assume that SOTs are particularly emerging at the interface between science and technologies.

Another challenge we are facing is, that in many cases, new knowledge is generated primarily in special communities, but the knowledge itself has to be applied by actors, who usually are not familiar with the knowledge field (Porter & Cunningham, 2005). Especially, with respect to SOT, this might pose a great challenge to the established industries, such as agriculture or food industry, if they for instance recover resources which in turn can be used in different industry sectors (Carraresi et al., 2018; Carraresi & Bröring, 2021). This may lead to incremental changes in the value chain or more disruptive alteration, as SOTs could enter completely new markets. Companies already promote incremental innovations in terms of process optimization to achieve sustainability (Hansen, Bullinger, & Reichwald, 2011). However, many companies fail to detect opportunities for more radical innovation striving for sustainability (Metz, Burek, Hultgren, Kogan, & Schwartz, 2016), as decisions might depend on existing capabilities within a firm (Petrick & Martinelli, 2012; Wiener, Gattringer, & Strehl, 2020). Thus, especially in the context of SOTs, which are also characterized by high interdisciplinarity (Borge & Bröring, 2017; MacLeod, 2018; McCormick & Kautto, 2013), a forecasting method is needed, which offers a comprehensive overview of the existing research and technology fields.

Beyond this, nowadays sustainability is often a strategic driver for new business (Kennedy et al., 2017), which might promote the emergence of SOTs on the one hand and make it necessary to evaluate them on the other hand. To achieve compliance with political agendas, such as the UN Sustainable Development Goals (SGDs), efforts in sustainability-oriented science as well as technology and innovation are increasing (Arash et al., 2020). In general, there are three basic drivers for environmental innovation, namely technology push in terms of resource efficiency, regulatory push, in terms of environmental laws and regulations and market pull, in terms of image or competition (Horbach, 2008; Rennings, 2000), which may additionally affect the emergence of SOTs (Akbari, Khodayari, Danesh, Davari, & Padash, 2020). Accordingly, and especially in this highly dynamic environment, technological foresight is essential to facilitate the understanding and anticipation of technological changes (Reger, 2001). We assume that SOTs are a suitable example for analyzing the interface between science and technology, as they might be both, driven by the development of technical applications (revealed in patents) by industry seeing the need for sustainable alternatives and basic research (revealed in publications) fostered by public research projects.

2.2.2 Measuring emerging technologies

It is not new that research claims for tools of “strategic intelligence” as input for decision making in innovation politics or industry (Kuhlmann, Boekelt, Georghion, & Guy, 1999). These tools and methods are elements of technological forecasting, which is again part of the more holistic technology foresight processes, that follow a systemic recognition and observation of technologies using gathered information including also people’s opinion and a variety of different methods (Cuhls, 2003; Reger, 2001; Rohrbeck, Arnold, & Heuer, 2007).

In that regard, literature reveals multiple different methodologies to forecast the future development of emerging technologies. On the one hand approaches can be subjective, based on expert opinions generated by e.g., interviews or Delphi studies. On the other hand, approaches can be objective such as S-curves (Bengisu & Nekhili, 2006). In the case of sustainability-oriented innovations, especially scenario techniques or life-cycle assessments (LCA) have been applied to evaluate the future potential of emerging technologies (Amann, Zoboli, Krampe, Rechberger, Zessner, & Egle, 2018; Berner, Dönitz, Westhofen, & Moller, 2016; Escobar & Laibach, 2021). However, bibliometric approaches play one of the essential roles in order to identify how and which new technologies emerge (Bildosola et al., 2017). In this context the most common tool to analyze emerging technologies is patent analysis, as patent statistics provide an objective, transparent and easy accessible data source (Haupt, Kloyer, & Lange, 2007; Ma & Porter, 2015; Song, Kim, & Lee, 2017; van den Oord & van Witteloostuijn, 2018). Patents reveal the manifested technological knowledge (Ávila-Robinson & Sengoku, 2017), which is for instance particularly true in the areas of chemistry (Asche, 2017). Bibliometric analysis of patents allows for the calculation of various indicators leading to the evaluation of the patent’s technological innovation potential (Zhang, Qian, Huang, Guo, Zhang, & Lu, 2017). In contrast, publications as another valuable source for measuring emerging technologies are a proxy for the scientific domain (Debackere, Verbeek, Luwel, & Zimmermann, 2002; Verbeek, Debackere, Luwel, Petra, Edwin, & Filip, 2002). In that regard, the majority of literature uses citation network analysis to identify trends and growth in specific research or technology areas or the mutual influence of different research topics (Ho et al., 2014; Kajikawa et al., 2008; Kajikawa & Takeda, 2008; Park, Yoon, & Lee, 2005).

Due to the immense growth of patent and publication data, it is not manageable anymore to solely rely on humans’ skills when trying to keep the overview of an emerging technological field. Thus, text mining is a suitable tool to assist in keeping track with the emergence of new technologies. (Kim et al., 2019; Porter & Cunningham, 2005). The textual similarities within the text mining approaches are often used to form different clusters for analyzing patent information in a more comprehensible way and to evaluate or predict the development of these clusters over time (Arts, Cassiman, & Gomez, 2018; Kim, Suh, & Park, 2008; Niemann et al., 2017; Tseng, Lin, & Lin, 2007). Semantic analysis by using patents as data source was also applied by Joung and Kim (2016) to monitor emerging technologies. Recent studies, however, show that a concurrent analysis of both, scientific literature and patented technologies contribute to the detection of the innovation trajectory of emerging technologies (Kwon, Porter, & Youtie, 2016). Drawing upon the literature stream on opportunity recognition (Baron, 2006; Wang, Fang, & Chang, 2015), firms might often not be aware of the scientific discoveries which may also improve their technological development and commercialization (Bandarian, 2007). Researchers claim that it is important to integrate different data sources to identify emerging technological trends (e.g.Cozzens et al., 2010; Nazemi & Burkhardt, 2019; Wustmans, Haubold, & Bruens, 2021). As Ma and Porter (2015) or Kwon et al. (2019) suggest, patent and publication data may complement each other, when identifying the scientific and technological impact of an emerging technology domain or identifying the technology development patterns and trends. This is specifically relevant for SOTs, as by increasing regulatory pressures and public research funding, an openly accessible and thus limited patenting communication of technological advances is more frequent. The more comprehensive assessment of both scientific and technological developments is thus necessary to capture emerging technologies (Hansen & Klewitz, 2012). An extant literature review shows that especially in recent years research on the detection of emerging technologies combined, among other data sources, especially patent and publication data (Table 2.1).

Table 2.1: Literature extract of research integrating both data sources, patent and publication data, to analyze the emergence of technologies.

Author	Focus of measure	Main methodological approach
Goeldner et al. (2015); van Looy et al. (2006)	actors (countries or organizations) being active in scientific research, technological development or both	citation network analysis
Ávila-Robinson and Sengoku (2017)	knowledge-building dynamics; country-level actors, and their interrelations in research leading to "techno-scientific networks"	
Shibata, Kajikawa, and Sakata (2010)	Comparison of structures of citation network of scientific publications with those of patents in the field of solar cells to detect new opportunities for industrial commercialization	
Winnink and Tijssen (2015)	Early detection of potential breakthroughs in science by measuring forward citations of individual scientific publications in subsequent publications and patents	
Rodríguez-Salvador *et al.* (2017); Engelsmann and van Raan (1994)	Co-occurrence and keywords clusterization technique; use of IPC classes to validate technology clusters	text mining / semantic analysis
Naumanen, Uusitalo, Huttunen-Saarivirta, and van der Have (2019)	Parallel identification of emerging topics in publications and patents through topic modelling	
Zhang, Zhou, Porter, and Vicente Gomila (2014); Zhou, Huang, Porter, and Vicente-Gomila (2019)	term clumping followed by the semantic analysis of SAO structures as input for technology roadmapping; (net effect analysis to identify relationships among key research topics)	
Ogawa and Kajikawa (2015)	Research areas are identified by clustering the citation network of academic papers	citation network analysis + semantic similarity analysis
Rotolo et al. (2017)	Depiction of emerging technologies over multiple base multiple base maps (i.e., geographical, social and cognitive space) across different time periods	overlay mapping

However, tools to support the detection of technological developments at the interface between science and technologies were already introduced by Engelsmann and van Raan in 1994. They first derived technological maps based on co-word and co-classification analysis of patent documents on different hierarchical levels from a broader macro to a technology field specific micro perspective. Second, as a means to identify technological fields at the interface between science and technology, they also derived research maps based upon co-word analysis of applied scientific publications in a particular field. Then in turn, the most important keywords found in the publication data were used to generate another patent set, which was used to derive a third co-word map called as the science and technology interface map. The visual comparison of the three maps may allow for the identification of different clusters on science, technology or interface level. However, their results referring to the technological field of optomechatronic also show, that the most important keywords or co-words appearing in patents and publications are fairly different, which makes the bridging of both data quite difficult.

In general, mostly citation network analysis or independent parallel text mining approaches are used to identify technology clusters in and across publication and patent data. In this context, research by van Looy et al. (2006) introduces the *science-technology relatedness* indicator, which measures the number of non-patent references listed in a patent, the number of companies contributing to scientific outputs (publications authored or co-authored by companies) and the number of actively contributing knowledge generating institutes (universities or public research organizations) within a certain technological field. This seems to be a valuable approach when striving for the identification of actors being active at the interface between science and technology. In their study, they found for instance that citation in patent documents to non-patent literature seems to be particularly relevant when developing technology in newer, emerging fields. However, the approach is less suitable when the primary goal is to depict the development of different emerging technologies in the first place.

Winnink and Tijssen (2015) also tackled the problem how to early anticipate emerging technologies and breakthroughs at the interface of science and technology. They argue that bibliographic data of potential breakthrough publications reveal certain characteristics such as relatively frequent and increasing forward-citations in other scientific and patent publications shortly after it was published.

‘‘Subject–action–object” (SAO) semantic analysis is usually applied in text mining of patent or publication documents to identify key components (S and O) and their semantic relationship (A) in the respective invention (technology) (Wang, Ren, Chen, Liu, Qiao, & Huang, 2019; Zhang et al., 2014). In addition to this, Zhang et al. (2014) present a combined approach, which uses “term clumping” followed by the semantic analysis of SAO structures in order to understand the relationships between problem and their solutions, which can finally lead to the depiction of problem and solution patterns in technology roadmapping.

Ogawa and Kajikawa (2015) measure the semantic similarity of patents and academic research clusters by introducing the patent relatedness indicator, which measures keyword relatedness between patents and the research clusters, which were initially identified by citation network analysis. Rotolo et al. (2017) propose overlay mapping techniques to integrate different contexts. However, their goal is to visualize the emergence of technologies across geographical, social and cognitive (WoS categories) spaces leading to base maps.

The focus of this paper is the depiction of emerging technologies on science and industry level aiming at a more holistic technical perspective. Due to time lags between citations, the occasional changes of categorization of patents into IPC or CPC classes/groups (Passing & Moehrle, 2015) and the fact that publications do not reveal a similar categorization system, this study applies a semantic analysis, in order to observe the emergence of new technological fields and their evolution over a course of time (Frischkorn & Möhrle, 2015; Niemann et al., 2017). Accordingly, this paper seeks to directly link scientific (publication) and technological (patents) knowledge based upon semantic similarity analysis to obtain a nuanced measure to identify emerging technologies and thus contributing to technological forecasting.

2.3 Methodological approach

2.3.1 Case description

Emerging SOTs and resulting products go along with high unfamiliarity for established companies. One example of an emerging SOT is the recovering of phosphorus from different side- or waste streams. The element phosphorous is an essential resource to boost growth of agricultural products, to stabilize food products or improve washing performance (Schipper, 2016). Despite the emergence of SOTs to recover phosphorus from different side- or waste streams, this resource is currently still predominately mined from finite phosphate rock (Mayer et al., 2016; Rittmann, Mayer, Westerhoff, & Edwards, 2011).

Phosphorus recovering technologies might contribute to decreasing the dependence on fossil resources and to a lower pollution of wastewater. Additionally, they might lead to improved food security and to an additional profit for companies extracting and selling the recovered phosphorus for further usage. Nevertheless, companies struggle with implementing such technologies (Le Corre, Valsami-Jones, Hobbs, & Parsons, 2009; Mayer et al., 2016). Many technologies are still in the laboratory phase, since academia and industry actors are uncertain about future market potential. Emerging technologies go along with the questions how they may deliver new features to satisfy customer needs and how they can compete with established technologies in terms of costs (Day & Schoemaker, 2000). As a result, emerging SOTs (i.e., resource recovery) have to compete with established, more cost-efficient technologies (i.e., traditional fossil extraction) (Sick, Bröring, & Figgemeier, 2018). However, initially innovation management faces the challenge to identify the relevant technologies, in order to assess their future potential, since those technologies have to be applied by industries (e.g., food industry or wastewater treatment plants), which were previously not in touch with the issued described above (Alkemade & Suurs, 2012; Carraresi et al., 2018).

In doing so, this paper refers to the emerging technological field of phosphorus recovery. Phosphorus can be recovered from various feedstock, such as agricultural residues, manure or wastewater (Rittmann et al., 2011). As wastewater or sewage sludge provide a high phosphorus recovery potential, more than 50 different technologies have been developed over the past years in this particular field (Egle et al., 2015). In general, technologies can be differentiated according to biological, mechanical and chemical processes and according to different access points (e.g., untreated wastewater, digested sewage sludge or sewage sludge ash) during the wastewater treatment. The technologies currently emerging in this domain range from simple processes such as precipitation to complex multi-step approaches. Biological phosphorus removal processes, for instance, rely on specific phosphorus accumulating microorganisms (bacteria), which bound the phosphorus in aerobic conditions and subsequently release phosphorus under anaerobic conditions (Tarayre et al., 2016). Most processes, however, combine biological phosphorus elimination with chemical processes such as ion exchange, crystallization or wet-chemical extraction. Multiphase reactions are often carried in fluidized bed reactors (Egle et al., 2015).

Phosphorous removal from wastewater treatment plants is already mandatory in many countries to prevent the introduction of phosphorous from human excrements or detergents into rivers and lakes which would otherwise lead to increasing eutrophication (de-Bashan & Bashan, 2004). However, since September 2017, in Germany for instance, a new regulation was passed saying that larger wastewater treatment plants must plan measures for the recovery of phosphorous and implement them by 2023 (BMUB, 2017). Accordingly, the need for more efficient phosphorous recovery technologies is increasing. So far, technologies are rather on a laboratory scale and are not implemented on a larger scale. Also, the new EU fertilizer regulation opens the European market for recycled fertilizer. This means, companies wishing to be ready in three years when the rule enters into force, need to identify and evaluate the emerging technologies now to take profound decision (ESPP, 2019).

2.3.2 Method description

The overall goal of this paper is to identify and evaluate emerging technological clusters over a course of time based on semantic similarity between patents and scientific publications. Therefore, we refer to the approach by Niemann et al. (2017), which relies on the assumption that similarities between the contents of patents are reflected by similarities in language (e.g., use of similar terminology) and extend this approach by bridging patents and scientific publications semantically in the manner of Wustmans et al. (2021), who bridged patent and trend data. Basically, our approach consists of four steps, which are presented in Figure 2.1.

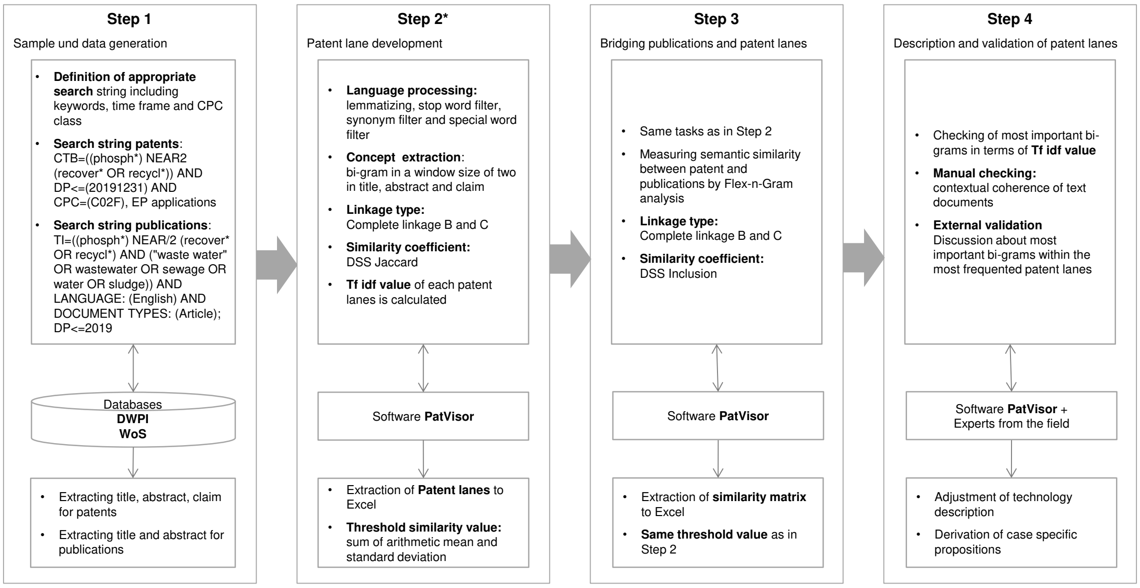

Figure 2.1: Methodological framework. Source: Authors.

* Step 2 is conducted according to the generic process by Niemann et al. (2017).

In step 1, appropriate keywords according to Egghe's (2008) formula of precision and recall relating to phosphorus recovery are identified. Due to the current situation in Europe with respect to the revised EU fertilizer regulation and the coming obligation to recover phosphorous from wastewater, our approach is applied on European patent applications filed at the European Patent Office (EPO)[1]. After an iterative process with more complex search strings, we eventually used the simple search string (*phosph* NEAR2 (recov* OR recycl*))* in the patent data base Derwent Innovation (DWPI) with the restriction to the CPC code C02F referring to wastewater treatment, in order to increase the precision of the technology field. We used patent applications, as we want to identify emerging technologies and it may take several years until a patent get granted. We included all patents, which were published until the end of 2019. After manual checking for completeness of title, abstracts and claims the data set contained 80 patent documents.

In the case of scientific publications, we limited our search for relevant documents in scientific articles' titles to gain fewer false positives in comparison to the extended search in articles' abstracts (Rotolo et al., 2017). Different to patents' abstracts, articles' abstracts often contain methodological terms or technical words, which do not represent the actual core of knowledge the given scientific article claims (Leydesdroff, 1989). As publications do not reveal a technological classification scheme as patents, we extended our search string by words

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[1] It should be noted, that patents which were only filed in individual European countries and not at the EPO were not included into our data set.

included in the description of the CPC class C02F, such as “wastewater” or “sewage” (see Figure 2.1). We extracted the publications’ title, abstract and publication year until 2019 from the Web of Science (WoS) database. After removing incomplete documents, the publication data set contained 386 documents.

Step 2 in our framework, the semantic similarity calculation of patent documents, encompasses several sub steps, following the approach by Niemann et al. (2017). The approach relies on the comparison of concepts, i.e., word combinations between textual parts in a specific window size, which is carried out in the software PatVisor[2]. As there might not be a single correct window size (Corman, Kuhn, McPhee, & Dooley, 2002), we selected a window of two regarding to the text being analyzed. In our case of phosphorous recovery, we often have a combination of adjective and noun (e.g., biological reactor), standing in a row, which give us useful insight into the content of the respective document.

First, however, several word filters were applied in order to eliminate all stop words and technology specific words, such as water, phosphorus or sewage sludge, as we already knew that those words are part of every document. Furthermore, linkage measurement and similarity coefficient to evaluate the similarity between textual elements (defined as concepts) have to be defined. According to Moehrle's (2010) four criteria, namely purpose of the study, distribution of patent’s size, distribution of identical concepts in patents and importance of multiple occurrence of identical concepts, may support the decision for the relevant coefficients for the individual semantic patent analysis. We chose the double single-sided (DSS) Jaccard coefficient (Eq (a)) combined with a complete linkage coefficient. Those documents were compared according to semantic similarity based upon bi-grams.

$$DSS\,Jaccard = \left(\frac{c_{i(j)} + c_{j(i)}}{c_i + c_j}\right) \tag{a}$$

$$DSS\,Inclusion = \max\left(\frac{c_{i(j)}}{c_i};\frac{c_{j(i)}}{c_j}\right) \tag{b}$$

With the following variables:
DSS Jaccard = Double-Single-Sided Jaccard
DSS Inclusion = Double-Single-Sided Inclusion calculation
c_i = count of terms within document i
c_j = count of terms within document j
$c_{i(j)}$ = count of terms of document i that are also included in document j
$c_{j(i)}$ = count of terms of document j that are also included in document i

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[2] PatVisor is an open access semantic analysis software, developed by the Institute of Project and Innovation Management at the University of Bremen (see https://patvisor.ipmi.de/, retrieved 27.02.2020).

Additionally, patent documents are aligned to a patent lane on the basis of application year and maximum similarity to a previous patent application. The patent lane depicts the development of a specific patent cluster over the course of time. As also suggested by Niemann et al. (2017), the threshold similarity value for putting a patent in a specific patent lane was defined by the sum of the arithmetic mean and a single standard deviation. Eventually, the measure of 'Term frequency - inverse document frequency' (Tf idf) (Eq (c)) is calculated for each patent lane, in order to extract keywords which specifically characterize the respective sub-technology (patent lane). The term-frequency refers to the absolute number of a specific bi-gram within all patents in a patent lane. The inverse document frequency serves as a quantifier of documents, which contain the respective bi-gram.

$$Tf\ idf_{k,s} = (tf_{k,s} * \log(\frac{c}{cf_k}))\forall_{k,s} \qquad \text{(c)}$$

With the following variables:
tf = term frequency
idf = inverse document frequency
Tf idf = term frequency inverse document frequency
k = index for terms
s = index for clusters
cf. = number of clusters containing the term
c = sum of clusters

In step 3, a pairwise semantic similarity analysis, in the manner of step 2, between all patent and publication documents is conducted. In order to align the number of publications to the respective patent lanes (technology-cluster/sub-technology), the same similarity threshold value as in step 2 between a patent and a publication is defined as a starting point. We used the DSS Inclusion coefficient (Eq. (b)) for analyzing the similarity, as the document size of publications is much smaller than the patent documents' size (Moehrle, 2010). This measures how much of the smaller number of concepts, i.e., bi-grams are included in the bigger number of concepts. Finally, indicators such as the ratio of publications per patent lane are calculated. As a consequence, results from the patent lane analysis can be bridged with publication data. This supports the further evaluation and determination of technology developments and future research potential.

In step 4, in order to appropriately describe and validate our technology clusters with respect to contextual coherence, we have pursued an expert validation. One of our co-authors being a trained biotechnologist manually compared the most important bi-grams according to the Tf idf value with the actual text of the patent documents in order to better grasp their content. Additionally, three external experts in the field of phosphorous recovery were interviewed. One expert was an engineer and researcher at university in the field of urban water management and is involved in building up pilot plants for phosphorous recovery. A second expert was also a researcher at university, holding degrees in process and environmental technology as well as chemical engineering, who also collected experience with phosphorous recovery technologies during her studies. A third expert was a scientist and chemical engineer in the domain of water and wastewater treatment at a private research institute which is also active in developing phosphorous recovery technologies. We presented our patent lane results and the respective most important bi-grams to all experts individually to obtain an independent assessment and thus increase external validity of our results. Accordingly, we describe the technology clusters and derive case specific propositions based upon our results and expert opinions.

2.4 Findings and discussion

2.4.1 Descriptive results

Overall, we can see that we are dealing with an emerging technological field with a steep increase in number of publications in the domain of phosphorus recovery from wastewater. However, this is currently not reflected in the number of European patent applications (see Figure 2.2). For 2018 and 2019, due to the 18-month time lag of a patent application being published, it has to be noted that in fact there were probably more patent applications in the last two years.

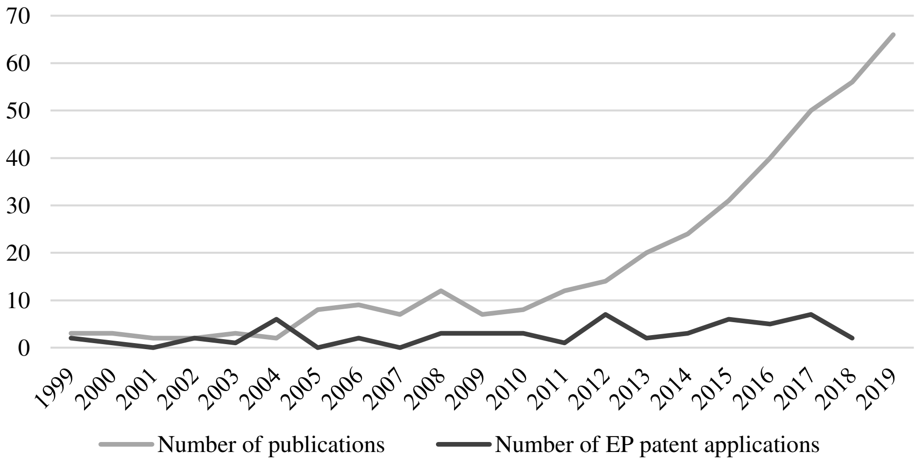


Figure 2.2: The development of European patent applications and the number of scientific publications along the application and publication year respectively. Source: Web of Science and Derwent Innovation

To identify emerging technologies in the domain of phosphorus recovery, we bridged publication and patent data by semantic analysis. Eventually, we obtained 80 EP patent applications and a corresponding set of 386 publications, which we included into the semantic similarity analysis. 56.25 % of the patent applications reveal a CPC code in the sustainability-oriented class “Y02”, which was established by the European Patent Office (EPO) a few years ago (EPO, 2016). That gives us another proof, that we are dealing with a case of SOTs. More precisely, CPC code Y02W "climate change mitigation technologies related to wastewater treatment or waste management" is the most common one among that particular CPC class in our patent sample. According to the WoS categorization scheme, publications mainly belong to the field of Environmental Science, Environmental Engineering or Water Resources. Figure 2.3 shows the top 10 categories, to which the publications can be assigned. Thus, it can be validated that most publications in our sample indeed refer to the research field of SOTs (i.e., phosphorus recovery).

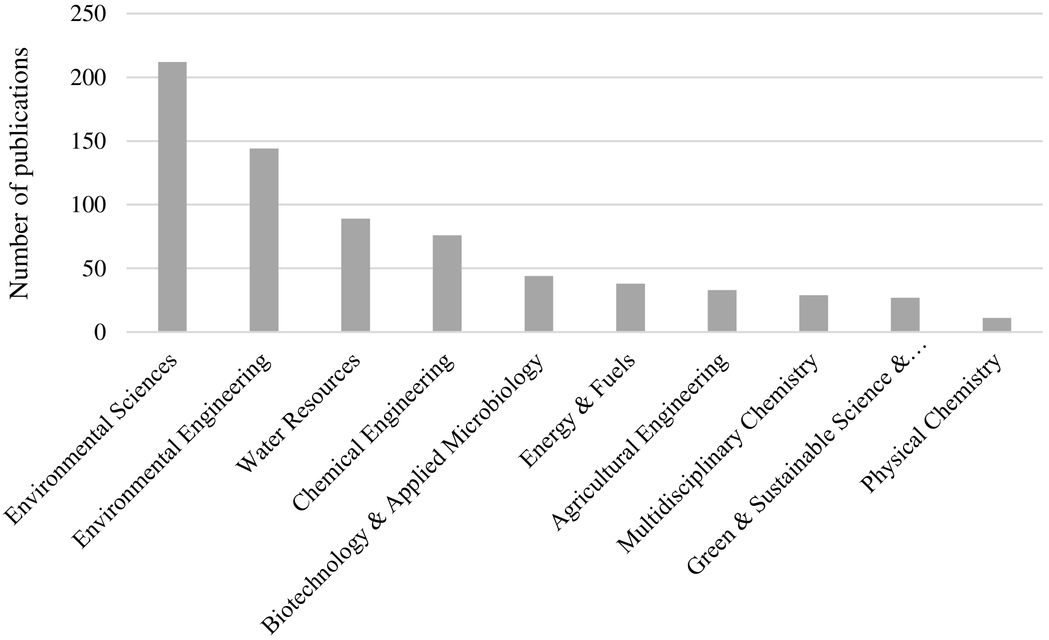
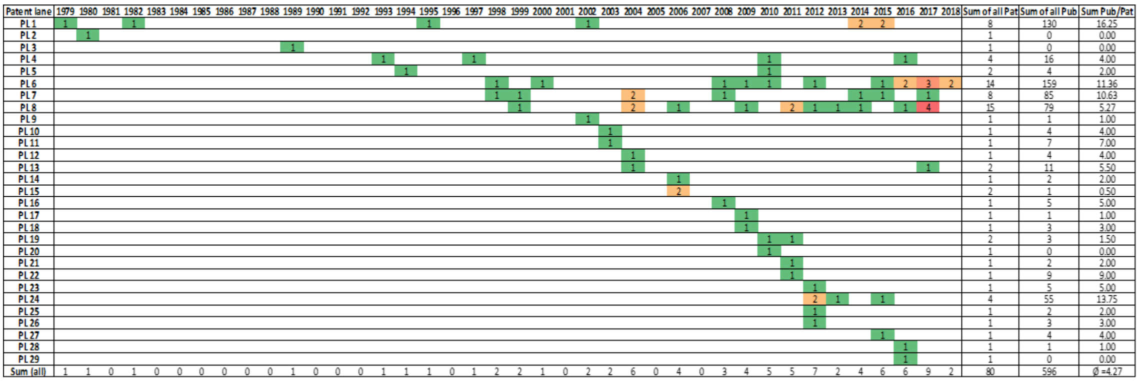


Figure 2.3: Top 10 Web of Science categories. Source: Web of Science (2020).

Remark: The sum of the publications within the WoS categories is larger than the total sum of publications which were included in the analysis, as publications can be matched to multiple categories.

Figure 2.4 shows the overall picture of all resulting 29 patent lanes, whereas Figure 2.5 zooms into the four most frequented patent lanes. The sum of the respective patents and publications as well as the ratio between the number of publications per patent are attached to the patent lanes.



Patent lane	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Sum of all Pat	Sum of all Pub	Sum Pub/Pat
PL1	1			1													1							1												2	2				8	130	16.25
PL2		1																																							1	0	0.00
PL3											1																														1	0	0.00
PL4															1				1													1						1			4	16	4.00
PL5																1																1									2	4	2.00
PL6																				1		1								1	1	1		1			1	2	3	2	14	159	11.36
PL7																				1	1					2				1						1	1		1		8	85	10.63
PL8																					1					2		1			1		2	1	1	1		1	4		15	79	5.27
PL9																								1																	1	1	1.00
PL10																									1																1	4	4.00
PL11																									1																1	7	7.00
PL12																										1															1	4	4.00
PL13																										1													1		2	11	5.50
PL14																												1													1	2	2.00
PL15																												2													2	1	0.50
PL16																														1											1	5	5.00
PL17																															1										1	1	1.00
PL18																															1										1	3	3.00
PL19																																1	1								2	3	1.50
PL20																																1									1	0	0.00
PL21																																	1								1	2	2.00
PL22																																	1								1	9	9.00
PL23																																		1							1	5	5.00
PL24																																		2	1		1				4	55	13.75
PL25																																		1							1	2	2.00
PL26																																		1							1	3	3.00
PL27																																					1				1	4	4.00
PL28																																						1			1	1	1.00
PL29																																						1			1	0	0.00
Sum (all)	1	1	0	1	0	0	0	0	0	0	1	0	0	0	1	1	1	0	1	2	2	1	0	2	2	6	0	4	0	3	4	5	5	7	2	4	6	6	9	2	80	596	Ø =4.27

Figure 2.4: Patent lanes based on 80 EP patent applications in the field of phosphorus recovery in the CPC class C02F. Source: Authors.

Remark: The total sum of publications is larger than the total sum of publications which were included in the analysis, as publications can reveal a certain similarity to more than one patent within a patent lane.

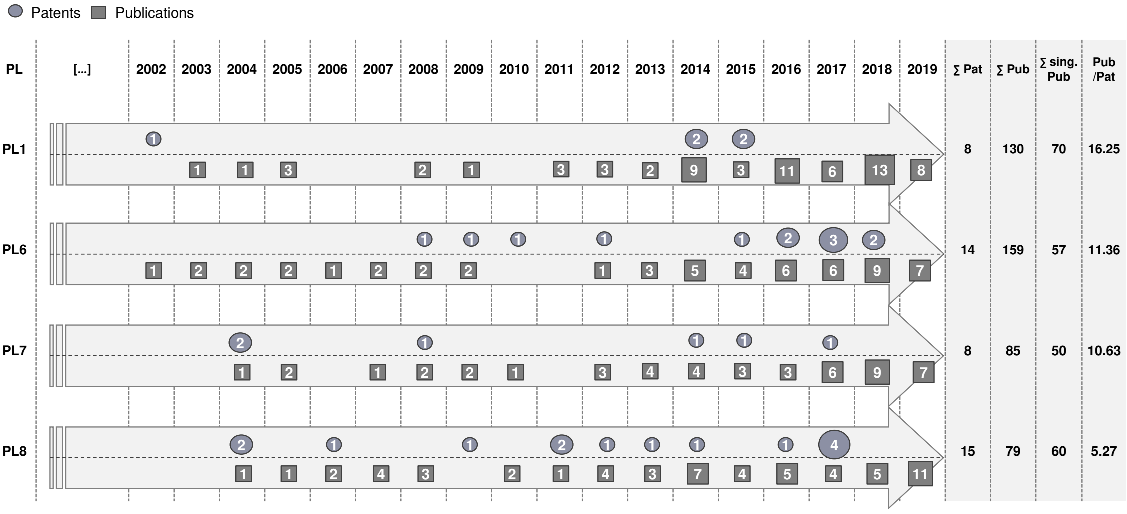


Figure 2.5: The four most frequented patent lanes. Source: Authors.

Remark: The sum of patent application and publications refers to the entire time from 1979 to 2019. However, in this figure only recent years from 2002 onwards are shown. In order to visualize the increase or decrease of patent applications or scientific publications over time, we reflect this in different sizes of circles (i.e., patents) and squares (i.e., publications). It has to be remarked, that we increase square size in a step of 4 due to better readability.

The threshold similarity value for putting a patent in a specific patent lane is ~0.048. The Results show that, over the course in time, four most frequented patent lanes (PL1, PL6, PL7, PL8) have emerged (cf. Figure 2.5). Together they encompass 56 % of all patents under consideration. PL1 belongs to the highly frequented technology clusters, however, its development starts in 1979 and adding of new patents expands over a very long time. That may imply that we are not dealing with an emerging technology, as fast growth and continuity are not given (Rotolo et al., 2015). Similarly, PL7 only contains one or two patent applications per year over a long period of time. Contrary, the other two patent lanes PL6 and 8 reveal a denser picture.

They start later and contain especially in recent years (i.e., 2017) up to four patent applications per year. This goes along with relatively fast growth and coherence, as signs for an emerging technologies according to Rotolo et al. (2015).

Interestingly, PL6, 7 and 8, which are one of the biggest technology clusters also gain patent applications in the recent years. There is only one other patent lane, i.e., PL13, with in total two patent applications, which reveal a patent application in 2017. That might be another sign for high relevance of PL6, 7 and 8.

18 patent lanes even encompass a single patent document only, which could mean that these technologies are quite unique without becoming a mainstream technology. However, it should be noticed that in some cases single patents might be also added to an existing patent lane, as only minor semantic variances could be responsible for the opening of a new patent lane. Remarkably, PL13 and 25, for instance do not belong to the highly frequented patent lanes in terms of patent applications, but they apparently reveal a quite high amount of publications (i.e., 11 and 55 respectively) containing a certain set of similar concepts. This is particularly interesting in PL25, containing 4 patent applications in recent years, but involving with 13.75 similar publications per patent within a technology cluster the second highest ratio of all patent lanes.

In order to obtain an indicator-based ranking of the most relevant patent lanes, four criteria, namely number of patents, number of all similar publications (including multiple matching between patents and a publication), number of single publications and the ratio of number of publications per patent for each patent lane were considered. The underlying assumption is that the higher the individual value, the greater the relevance of the respective technology clusters. Thereby, the ranking of "1", for instance, indicates the greatest relevance, whereas "4" indicates the least relevance among these sub-technologies. Eventually, we subsumed all individual values to obtain a ranking based upon multiple data. Table 2.2 shows the results for the most frequented and thus most relevant patent lanes.

Table 2.2: Evaluation and ranking of most relevant patent lanes. Source: Authors.

Patent lane	Number of patents	Number of all publications	Number of single publications*	Ratio (Number of publication/patents)	Evaluation	Ranking
PL1	8	130	70	16.25 (8.75)**	3+2+1+1=7	1
PL6	14	159	57	11.36 (4.07)	2+1+3+2=8	2
PL7	8	85	50	10.63 (6.25)	3+3+4+3=13	4
PL8	15	79	60	5.27 (4)	1+4+2+4=11	3

*The number of single publications refers to the individual publications, which are matched to the respective patent lane.

** The number in brackets reveals the ratio with regard to the number of single patents.

Interestingly, PL8 for instance includes the most patent applications; however, by bridging these results with the number of publications attached to the patent lane, it is only positioned on the third place. It might be concluded, that the technological field of PL8 is less developed in academia than on technology level with respect to patent applications. On the other hand, if only taking the patent applications into consideration, PL1 was not identified as such relevant. However, the bridging of similar publication documents shows, that PL1 was enriched by many new publications notably in recent years (cf. Figure 2.5). This, eventually, could reverse the previously made assumption, that PL1 does not cover an emerging technology and reveal that more technology transfer in this particular cluster is necessary. Accordingly, the semantic bridging of both data sources can provide another perspective when evaluating the relevance of an emerging sub-technology.

Whereas the previously described patent lanes contain the ratio of similar publications per patent, Figure 2.6 shows the development of the ratio of similar patents per publications mapped over the course of application and publication year, respectively. Overall, older publications have more similar patents. More recent publications have less similar patents. This is in line with the general concept of technology life cycle, where basic research (i.e., publications) is followed by applied research (i.e., patents) (Watts & Porter, 1997). In our case, this leads to the assumption, that in future more patents referring to recent publications on phosphorus recovery describing specific concepts may follow.

However, as for instance Curran, Bröring, and Leker's (2010) *weighted average year* indicator shows, it may also depend on the industry or research context, if first publications or first patents appear. In our case, it should be also noted that for patent data we used the application year as a base line and for publications the publication year. Both dates are the closest available references to the initial point of time when the technology was first discovered or developed. Also, it has to be noted that our sample only encompasses patents until 2018 due to the time lag between application date and being publicly available, which might also explain why later publications do not yet have many corresponding patents.

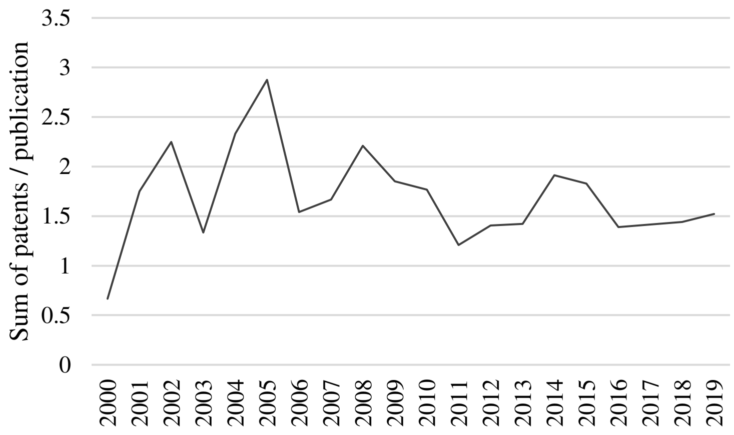


Figure 2.6: The development of the ratio of similar patents per publication according to the publication year of the publication year of the scientific publication. Source: Authors.

Remark: The graph shows the moving average over two years, in order to get a slightly smoother graph

2.4.2 Labelling and validation of patent lanes

In the following, we again focus on the four most frequented patent lanes to exemplary describe the technological fields depicted by a patent lane. The use of bi-grams according to the highest Tf idf values of a particular patent lane including text from title, abstract and claim suggested by Niemann et al. (2017) is in our case of limited suitability to describe the overall technology cluster, as often only one document within the patent lane contains the respective bi-gram. The frequent repetition of this bi-gram in the patent's claim section leads to the high Tf idf value. However, we strive for a more holistic description of the entire technology cluster and not a single patent document. Accordingly, we exemplary generated four documents for PL1, 6, 7 and 8, each containing only title and abstract of all patents belonging to the respective patent lane. Again, we considered the TF idf values of the four patent lanes, neglecting the remaining patent lanes. For each patent lane we selected the top 10 bi-grams according to their highest TF idf value. In some cases, they overlap with the most important bi-grams in the entire text document, whereby this approach allows for a more solid description.

Table 2.3 shows the top 10 bi-grams according to the highest Tf idf values derived from this approach. After cross-checking with experts and taking all bi-grams into consideration, it can be summarized that most technologies for phosphorus recovery rely on a sequence of multiple processes consisting of anaerobic and aerobic steps aligned with phosphorus uptake by microorganisms. However, PL1 rather focuses on acidic solutions and electrodialytic separation of heavy metal, which is associated by experts with phosphorous recovery from sewage sludge ash, one outcome of the wastewater treatment. PL6 encompasses patent applications predominately referring to the sequential treatment of wastewater, resulting in different separation phases covering liquid, filtrate or digestion phases. Although this patent lane was the most challenging one for experts to grasp the overall technology field, one expert understood this cluster as rather encompassing mechanical (e.g., “filtrate phase”) and biological (e.g., “digestion phase” and “anaerobic phase”) processes. In PL7, the focus lies on the operationalisation of ammonium ions or magnesium salts as to foster precipitation of phosphorus from sewage sludge for extraction. A prominent exemplary patent application assigned to PL7 is a patent filed in 2008 by the Berlin’s water companies, which claims phosphorous recovery from sewage sludge. It is a chemical-physical process which produces magnesium-ammonium-phosphate (MAP) – presenting a high-quality mineral slow-release fertilizer, which is also commercially available (Berliner Wasserwerke, n.d.). PL8 encompasses patent applications mostly focussing on the composition of the reactor itself characterized by the relevant bi-grams “reaction tank” and “digestion tank”. Additionally, this patent lane refers to the technology of crystallization which allows for the subsequent separation of solid crystallization products through solid liquid separation. However, this technology cluster was quite difficult to summarize by our experts, as the most important bi-grams in terms of Tf idf do not evoke a coherent association with a particular technology field.

To get even more insight into the bridging of patent and publication data, we exemplary zoomed into PL1, as this was a technology cluster, which we were able to describe most confidently. For instance, a patent application (EP3041795A1) assigned by the Technical University of Denmark in the year 2014 at the EPO relates to a process for separation of heavy metals from a suspension comprising heavy metal containing particulate material, in which the heavy metals are removed by the use of the electrodialytic remediation set-up. It is a well representative patent in PL1. It reveals in total 39 similar publications published between 2001 and 2019 in our sample. To exemplary check the validity of the semantic bridging of patent and publication data, we investigated all seven publications published by the same inventors from the Technical University of Denmark in our sample, if they are similar to the respective patent, as we assume that these researches write about similar technologies within scientific publications. Indeed, five out of these seven publications were similar to the patent application. In total, six of them reached the similarity value to one of the patents within PL1.

Our initial goal, to provide insight into particular phosphorous recovery technologies, such as different precipitation reactions, is still not entirely achieved with our approach. What we found out while showing our results to experts in this field is, that our technology clusters rather give an overview of different technologies used for different feedstock from which phosphorous might be recovered in waste water treatment. Overall, our external validation with technological experts shows that PL1 presents the most coherent picture of a technological domain in the area of phosphorous recovery from wastewater, namely technologies for phosphorous recovery from sewage sludge ash. It is currently the most promising technology for phosphorous recovery, as the sewage sludge ash reveals a quite high amount of phosphorous. Also, experts confirm our indicator-based ranking that this is currently the most prominent and promising technology cluster also when it comes to implementing phosphorous recovery technologies in pilot plants. This is an interesting finding, as it is another proof, why relying on a single data source, such as patents only, is not reliable when evaluating an emerging technology. Accordingly, our proposition is, that the number of similar publications assigned to PL1 shows that this technology cluster is much more represented on the science level, which might be in future also reflected in patent data or even market implementations of phosphorous recovery technologies.

Table 2.3: Description of the most frequented patent lanes PL1, PL6, PL7 and PL8 by the most important bigrams according to the Top 10 Term frequency – inverse document frequency (Tf idf). Source: Authors.

	PL1	PL6	PL7	PL8
	heavy metal leach solution electrodialysis stack material particulate filtrate heavy metal particulate compound precipitate acid hydrochloric acidify solution ash dissolve	liquid phase filtrate phase phase phase digestion phase effluent phase phase solid liquid solid nitrogen phase phase present anaerobic digestion	ammonium magnesium aqueous solution dirt particle ammonium ion coarse solid crystallisation tank filtrate solid agent coalesce coarse particle concentration high	reaction tank cation exchanger liquid salt biological reaction electrode sacrificial crystal filtrate crystallization reaction digestion tank hydrolyse urine magnesiumcontain material
Focus	Acidic solution + electrodialytic separation	different separation phases	sludge water processes; operationalisation of ammonium ions + magnesium salts	reactor composition

2.4.3 Reflection on the bridging approach

In order to reflect on the bridging approach, in this section we first highlight the identified benefits of semantically bridging patent and publication data in light of current literature. Second, we provide insight into the sensitivity of our bridging approach. Finally, we discuss some restrictions of the method and provide some suggestions to extend our approach.

Using text to identify technological novelties allows for avoiding the use of patent subclasses or citations, which might suffer from examiner bias (Arts et al., 2018). Furthermore, the patent lane analysis allows for detecting the starting point of a new emerging sub-technology, which is marked by the beginning of a new patent lane. Thus, it allows for a much more graduated differentiation of technological novelty than prevailing bibliometric approaches. This is particularly important if within the overall technology field, it is rather difficult to maintain an overview, as it is in the case of SOT, such as phosphorus recovery, where multiple different sub-technologies emerge.

Also, measured by the patent lane's number of patent applications over a period of time, further attributes for emerging technologies, i.e., growth and coherence (Rotolo et al., 2015), can be operationalized. Also, the underlying semantic analysis adds to the classical citation analysis in terms of timely availability (Liu, Yu, Janssens, Glänzel, Moreau, & Moor, 2010). Eventually, we provide a new indicator to reflect the ratio of scientific (publication) vs technological (patents) knowledge in a given domain. Adding publications to the technology clusters might lead to a different evaluation of the patent lane. Thus, the evaluation of the standard criteria characterizing an emerging technology based on single data sources might be highly limited.

However, one has to be careful in interpreting the ratio of publication per patent in absolute terms, as future research involving more experts from the field needs to validate the threshold value. This ratio should rather be interpreted in relative terms, as it allows for the comparison or ranking of technology clusters. An increase of the threshold value to for instance 0.06 shows that the number of similar patents per publications within the most frequented patent lanes 1, 6, 7 and 8 in total almost evenly decreased by ~35 %. Only the number of similar publications per patent within patent lane 8 disproportionately decreased by ~50 %. However, that still does not alter the ranking calculated in Table 2.2; it rather strengthens the argumentation that the technology field in patent lane 8 is less reflected in scientific articles than the others.

Our approach of semantic similarity analysis provides a fast clustering of sub-technologies and certainly helps to limit the search domain to track important emerging technologies, which may in turn facilitate decision processes. Accordingly, the method may support technological forecasting and thus accelerate the entire technology foresight process (cf. Rohrbeck et al., 2007). However, in order to obtain a deeper understanding of why these technologies belong to a specific cluster, a cooperation with experts in this field to validate the findings seems crucial, especially if the company has limited expertise in the field.

Our interviews with experts (e.g., chemists or engineers) active in the field of phosphorous recovery revealed that it is important to discuss the results, since not all clusters can be intuitively understood. The interviews also showed that the interpretation of our technology clusters by means of the most important bi-grams depends on the individual perspective of the researcher or engineer. Our results help to get a more abstract overview of the field with respect to several terms which are associated by experts with certain technological areas. In our case, that means that the patent lanes were rather assigned to technologies for phosphorous recovery from different feedstock (e.g., sewage sludge or sewage sludge ash) within a wastewater treatment facility than to different types of recovery.

In order to match the publications to the respective patent lanes, the same similarity threshold value as for the patent lanes was used to be consistent. This assumption can be criticized, since the language in scientific papers and patent documents is per se slightly different. Although, we have manually checked the suitability of the threshold value of 0.048, future work needs to carefully validate this threshold value especially for the bridging of patent and publication data while possibly using a quantitative approach. Our analysis shows that the bridging of patent and publication data by means of textual analysis is still challenging to validate, as the abstract of a publication only reveals restricted information on a particular technology. Scientific publications are a means to understand developments in science but less so to describe concrete technological applications. Future research may also use the keywords assigned to the publications to label the clusters and compare it to our labelling approach using the Tf idf indicator of the patent data.

Furthermore, the semantic bridging might be compared with for instance the *science-technology relatedness* indicator introduced by van Looy et al. (2006) (cf. section 2.2). Also, other semantic similarity approaches, such as vector space modeling, might be applied to validate our clustering results (Hain, Jurowetzki, Konda, & Oehler, 2020). Although we already discussed our results with a few experts possessing the technological knowledge, identified technology clusters could be further validated by systematic, interactive forecasting methods, such as a structured Delphi method, scenario technique or collaborative open foresight (Reger, 2001; e.g. Wiener et al., 2020). Furthermore, to dive deeper into the technology clusters, further indictors, such as the granting or citation rate or the international scope of the patent applications, could be calculated (Block et al., 2018; Ernst, 2003).

Our secondary data used in this paper is limited in terms of deriving statements about real market implementation of the technologies. It may further be interesting to combine other data sources than only patent and publication data to obtain more strategic insight into the evolving technology clusters and the real market. Parraguez, Škec, e Carmo, and Maier (2020) for instance used industry databases of R&D pilots and facilities and descriptions of research and innovation projects (e.g., R&D projects funded by the European Commission), which were bridged with publication and patent data by means of text mining analysis. Moreover, Hain et al. (2020) for instance introduced an integrated market-technology perspective in the wind and electric vehicle sector, which incorporates different key market development indicators, such as installed capacity of wind energy or the stock of electric vehicle, which can be compared to the technology development by means of patents in the field. However, in our case of phosphorous recovery the integration of the market perspective is not an easy task, as we are still at the very beginning of implementing phosphorus recovery at a commercial scale.

2.5 Conclusion

Our study proposes a framework for bridging patent and publication data while analyzing their semantic similarity. We apply the patent based approach by Niemann et al. (2017) on the highly dynamic field of SOTs and additionally combine it with publication data, while focusing on the case of phosphorous recovery. Thus, the evaluation of emerging SOTs can be built upon a broader range of information and likewise enables to integrate an ever-increasing amount of textual data. Our results lead to the conclusion that in the particular case of phosphorus recovery from wastewater four major sub-technologies (patent lanes) emerge. These patent lanes encompass in total the most patent and publication documents, which supports their relevance on technological and science level.

We used the total number of patents, the number of all similar publications, the number of single publications and the ratio of number of publications per patent for each patent lane to establish an indicator-based ranking of the technology clusters. The exemplary ranking of the four most frequented patent lanes shows that the sum of patent documents may reveal a different order than the sum of publications or the ratio of publication per patent within a patent lane. Also, we could show that, broadly speaking, more recent publications have less similar patents than publications already published in earlier years, which might lead to the proposition that in future more patent applications may follow. However, future research needs to validate these findings, as this phenomenon might also depend on the specific research or industry field. Whereas publications reflect the state-of-the art of science, patents describe the inventive developments in a technological domain. However, publications from applied research could even represent technological developments better than patents (Engelsmann & van Raan, 1994). Thus, the bridging of patent and publication data might support the identification of emerging technologies as well as the evaluation of their future relevance.

Implications for forecasting of emerging technologies

Theoretically and methodologically, this paper contributes to the literature of technological forecasting by combining patent and publication data to identify emerging technologies based on similarity analysis. Whereas previous literature primarily integrated both, patent and publications data, through parallel analysis (Goeldner et al., 2015; Naumanen et al., 2019), or bibliometric approaches such as co-authorship or co-citation of patent and publications often suffering from time lags (Narin, Hamilton, & Olivastro, 1997; Tussen, Buter, & Van Leeuwen, 2000), the semantic similarity analysis provides a direct technology linkage (Wustmans et al., 2021). This provides, in preparation for a more systemic (corporate) technology foresight process of emerging technologies, a good starting position for a subsequent dialogue between key actors with different views and experiences in the technological domain (Wiener et al., 2020).

Implications for SOTs

The fairly high number of different patent lanes and the fact, that 65 % of all patent lanes only encompass a single patent document might additionally underline the initially described dynamics of SOTs, connected to the pushing regulatory challenges. Also, our research adds to the extant literature on phosphorous recovery, which has mainly focused on the evaluation of different technologies from the technical or resource management perspective by estimating e.g., recovery efficiency or waste flows (Amann et al., 2018; Jedelhauser & Binder, 2018; Roy, 2017). Accordingly, our research supports the evaluation of phosphorus recovery technologies from a strategic technology management perspective aiming at technology foresight. This is particularly relevant, as companies are also engaged in directing their business activities towards more sustainability by developing SOI (Klewitz & Hansen, 2014).

Implications for managers

Our approach provides a technological forecasting tool, which might help managers gaining a first overview of the research and technology landscape in the field. Although, from a company perspective, more steps would probably need to follow, it helps in detecting their companies' position within a technological field in comparison to the competitors. However, depending on the prior knowledge of the manager the subsequent evaluation of the results has to be done in collaboration with researchers or engineers in the field (Reger, 2001). Thus, in order to guarantee sense making of our approach, we argue, that interdisciplinarity plays an important role in the evaluation of the emerging technologies in general but also particularly emerging SOTs. It might support companies aiming at valorizing by-products from their production process to identify appropriate technologies as well as, if including patent assignee, potential collaboration partners for future projects. Although, we applied the approach on an emerging SOT, is can be also used for other technological domains, if the following conditions are met: (1) The technology has to be patentable, (2)) the maximum of 200 patents should not be exceeded to allow for the derivation of patent lanes based upon semantic similarity analysis (see Niemann et al., 2017), and (3) the technological domain needs to be reflected in scientific research by means of publication data.

As mostly companies or private research institutes appear as patent assignees, academia might thus find relevant companies as levers for technology transfer. Additionally, for academia, this approach might be useful to match existing technologies in terms of patents with current scientific work to identify those sub-technologies where current research is building on. Eventually, the depiction of the development of different emerging technologies by means of patent lanes and the bridging of publication data for phosphorus recovery may serve as a criterion for academia, managers or policies while deciding upon investing in a particular emerging technology striving for transition to a more sustainable economy.

3 Assessing emerging technologies from a company perspective

Chapter 3 answers the following research questions:

RQ 2: What are the criteria for selecting a sustainability-oriented technology from a value chain spanning perspective in the case of the bio-based economy?

RQ 3: How do the perceptions of relevancy of these criteria differ between stakeholders along value chains of the bio-based economy?

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An early version of the paper has been presented at the R&D Management Conference, 6.-8. July, 2021, Glasgow (awarded with best PhD paper and best paper in track).

3.1 Introduction

Sustainability is the imperative across all industries (Loorbach & Wijsman, 2013; Rigall & Wolters, 2019) accompanied by long-term and multi-dimensional sustainability transitions that shift established socio-technical systems to more sustainable modes of production and consumption (Markard et al., 2012). Several sustainability transitions can be observed in different industries. For example, the energy industry is driving towards renewable energy sources, the agricultural industry is aiming to advance technologies for a more efficient use of resources, or, more general, the socio-technical regime of a fossil-based economy is heading towards an economy built upon bio-based and renewable resources (Geels & Schot, 2007; Vandermeulen et al., 2012). Sustainability transitions are initiated by different drivers, among others by emerging technological inventions (Geels, 2002). Implementing such inventions, or so-called sustainability-oriented technologies (SOTs) (Block et al., 2021), within a company can take place autonomously requiring less interaction with other stakeholders along the value chain. But some SOTs also show rather systemic characteristics and, thus, require interaction between and agreements from different stakeholders along the value chain. Additionally, SOTs are either of incremental nature by showing a limited degree of innovativeness or of radical one.

Nevertheless, all SOTs aim to contribute to sustainability in different ways. From a business perspective, sustainability encompasses economic, social and ecological aspects in a ‘triple-bottom line’ (Dyllick & Hockerts, 2002). SOTs that are for instance emerging from autonomous and incremental innovations are usually adopted easily by individual firms within the current socio-technical regime (Bröring, 2008; Kiefer et al., 2019). The aim of autonomous and incremental innovations is to reduce the environmental impact of current production methods through, e.g., selective input substitution or the implementation of end-of-pipe technologies for waste treatment, by-product valorization and emission reduction (Bröring et al., 2020; Frondel et al., 2007; Hellström, 2007; Kemp & Soete, 1992). Contrary, while still mainly focusing on the environmental impact, systemic SOTs with either incremental or radical characteristics often do not reach full exploitation if their influence on other parts of the value chain are not considered (Hellström, 2003; Vandermeulen et al., 2012). For example, within the European GMO market consumer resistance was initially underestimated and not taken into full consideration (Vandermeulen et al., 2012).

From innovation ecosystem research we know that a given innovation often does not stand alone, but rather depends on other changes in the firm’s environment leading to technological interdependence (Adner, 2006; Adner & Kapoor, 2010). This particularly applies to systemic innovations, requiring a high level of different actors’ involvement, but also to radical innovations, revealing a large degree of innovativeness. Systemic innovations include a stakeholder-spanning perspective along different industries and value chains, and the consideration of stakeholders' heterogeneous exposures to and expectations from SOTs (Alkemade & Suurs, 2012; Bröring, 2008; Kiefer et al., 2019; Teece, 2002).

Additionally, from transition theory research we know that a sustainability transition fostered by emerging SOTs cannot be achieved within company or industry boundaries alone (Geels, 2002; Geels & Schot, 2007). For example, in the bio-based economy a sustainable way of producing fuels or plastics is the concept of biorefinery converting biomass into the respective products. Biorefineries, however, not only require feedstock, i.e., biomass, but also innovations originating from various fields, such as bioengineering, polymer chemistry, food science or agriculture (Ohara, 2003). Accordingly, benefits of such systemic innovation "can be realized only in conjunction with related, complementary innovations" (Chesbrough & Teece, 2002).

However, within the intersection of management and sustainability transition literature, little is known about the incorporation of the systemic dimension into the selection and implementation process of SOTs (Köhler et al., 2019). Extant studies focus on tools and methods for technology selection or evaluation for practitioners but miss a particular context, such as the sustainability transition (Heslop et al., 2001; Schimpf & Rummel, 2015). However, as sustainable innovations are often affected by external drivers, such as regulations or market turbulence (Qiu, Hu, & Wang, 2020), technology evaluation might be contingent on the circumstances of an unstable environment (Tidd, 2001). Other studies concentrate on technologies' sustainability evaluation (Dewulf & van Langenhove, 2005; Escobar & Laibach, 2021) or looked at sustainability assessments of value chains and entire systems (Martin, Røyne, Ekvall, & Moberg, 2018; Ren et al., 2017).

But, literature would benefit from an exploration of how different industry sectors along a value chain evaluate SOTs with systemic characteristics. This is especially needed since the character of many SOTs can be classified as systemic and industry boundary spanning (Bohnsack et al., 2020; Bröring et al., 2020), which hence require coordination across different partners to ensure resource complementarity and interfaces. Thus, for business to reach a sustainability transition, it seems pivotal for the implementation of SOTs to understand and consider selection criteria from different stakeholders along the value chain. Such a systemic perspective on SOT evaluation is so far lacking in the literature. It is barely explored how different industry stakeholders, i.e., industries along a value chain, evaluate the relevancy of different evaluation criteria. Therefore, our research is guided by the following questions that are applied to the case of the bio-based economy (reasoning see below).

RQ2: What are the criteria for selecting a sustainability-oriented technology from a value chain spanning perspective in the case of the bio-based economy?

RQ3: How do the perceptions of relevancy of these criteria differ between stakeholders along value chains of the bio-based economy?

To answer these research questions, we collect and evaluate different SOT selection criteria from stakeholders along value chains within the bio-based economy. It should be noticed that we do not differentiate between SOTs resulting from radical or incremental innovations, as the technology's characteristic of being either incremental or radical to the organization might emerge as a selection criterion for SOTs. Our research objective is to foster the technology transfer of emerging SOTs from lab scale towards commercialized sustainability-oriented innovations by engaging the perceptions of various business stakeholders along the value chains in the bio-based economy. These value chains usually start in the agricultural industry as a raw material provider heading towards various consumer industries that eventually apply bio-based (and recycled) materials in consumer products. We chose the case of the bio-based economy, as a variety of systemic changes driven by SOTs currently occur along its value chains, such as the rise of biorefineries and the need to adapt bioengineering to feedstocks affecting downstream product qualities (Bröring et al., 2020; Laibach et al., 2019). Additionally, the chemical industry is an important stakeholder in several bio-based value chains. Especially, the chemical industry is a strong research sector and, thus, a major driver of new technologies and innovation (Kirner & Som, 2016). However, to implement new technologies and align technology push and market pull, stakeholders in the chemical industry depend on expectations and technology selection criteria of downstream actors in other industries, such as customers´ customer in the consumer industry (Rigall & Wolters, 2019). The same seems to apply to emerging SOTs, as companies from various industries have different priorities when integrating sustainability in their product portfolio (Villamil & Hallstedt, 2021). Currently, many SOTs fail in the challenge of moving from laboratory scale to commercial application, since they still have to compete with prevailing, often less sustainable but economically viable, technologies. To overcome such challenges, companies strive for a value chain spanning perspective when searching for new sustainable solutions (BASF, 2020; Rigall & Wolters, 2019). To implement a value chain spanning perspective, we draw upon group concept mapping (GCM). GCM is a mixed-method approach that includes the perception of various stakeholders towards a research problem under consideration (Kane & Trochim, 2007). GCM was already applied for answering manifold research questions, such as what are factors influencing technology transfer (Borge & Bröring, 2020) or what are drivers enhancing or limiting the emerging value chains in the bio-based economy (Berg, Cloutier, & Bröring, 2018). Based on the results of our GCM study, we provide a conceptual framework of technology selection criteria from a value chain spanning perspective striving for the implementation of SOTs on the way from a fossil-based towards a bio-based economy. While using the GCM approach, we identify areas where different actors have similar or different perceptions in technology selection across bio-based value chains. This allows identifying areas which potentially need some alignment to facilitate the technology transfer in the context of sustainability transitions.

The remainder of the paper is structured as follows: First, we provide the theoretical framework to characterize different types of SOTs and structure major challenges of actors associated with implementing systemic SOTs along a value chain. Further, we show prevailing technology selection criteria. In section 3, we introduce the research design and argue for the GCM approach that encompasses various steps, such as stakeholder selection, data collection and data analysis. Subsequently, in section 4, we present our results. In section 5, we discuss the results by comparing the identified selection criteria and their perceived relevance with prevailing technology selection criteria. In section 6, we conclude that there are on the one hand criteria for the evaluation of SOT which are highly relevant throughout the value chain and on the other hand criteria which are less or more relevant for a particular stakeholder type (group of actors belonging to a certain part of the value chain).

3.2 Theoretical background and literature review

3.2.1 Sustainability-oriented technologies

Within the concept of eco-innovations, SOTs can be categorized as technological innovations, that reduce the firm’s activities’ impact on the environment (Rabadán, Triguero, & Gonzalez-Moreno, 2020). While drawing upon the general concept to scrutinize innovations (Teece, 1996) and frameworks incorporating the sustainability-oriented dimension derived by Hellström (2007) and Bröring et al. (2020), we particularly differentiate SOTs according to the level of change they induce, i.e., autonomous vs. systemic. Whereas autonomous innovations can be successfully handled by a single company, the success of a systemic innovation depends on the involvement of different actors and complementary innovations from the entire industry (Bohnsack et al., 2020; Bröring, 2008; Teece, 2002). Autonomous innovations can also be related to component or modular innovations, whereas systemic innovations can be related to architectural innovations (Henderson & Clark, 1990).

Beside the level of change they induce, SOTs can be differentiated according to their degree of innovativeness. SOTs may encompass incremental (e.g., incremental improvements in material and energy efficiency) or radical innovations (e.g., extraction of valuable compounds / resources enabling new value chains), which are both equally important when pursuing greater environmental sustainability (Bröring et al., 2020; Szekely & Strebel, 2013). However, in order to achieve the technological substitution pathway and thus the replacement of the old socio-technical regime, i.e., the fossil-based system, radical innovations are necessary (Geels & Schot, 2007; Kemp et al., 1998; Vandermeulen et al., 2012). Once a new dominant design is established, incremental innovations to improve the new system are more likely to be observed (Abernathy & Utterback, 1978). Accordingly, besides optimizing existing production systems, it can be valuable to pursue exploration by investing in radical innovations leading to an increasing sustainability (Loorbach et al., 2010). Thus, although this paper is not excluding one or the other type of innovation, we particularly address emerging SOTs referring, according to Rotolo et al.'s (2015) understanding of emerging technologies, to “radically novel and relatively fast growing technolog[ies] […] with the potential to exert a considerable impact on the socio-economic domain(s) which is observed in terms of the composition of actors, institutions and patterns of interactions among those […]” (p. 1828).

In line with Kuckertz and Wagner's (2010) definition of sustainable entrepreneurship, we are aware that all kinds of technologies can foster or hinder sustainable development. In the remainder of this paper, we, however, focus on those technologies intentionally positively contributing to sustainable environmental development when using the term SOT. Although environmental SOTs may also contribute to social sustainability, the focus relies on the technologies’ environmental sustainability. We particularly tackle the challenges associated with those SOTs incorporating a systemic character by requiring different actors within a value chain to change their processes or even deviate from their previous business bases (Kiefer et al., 2019). An exemplary concept is the use of agricultural biomass in a cascading manner, where waste and by-products of one production process serve as inputs for another production process aiming at minimum resource consumption and waste production. Figure 3.1 exemplary illustrates various emerging value chains in this bio-based economy, which go along with systemic changes.

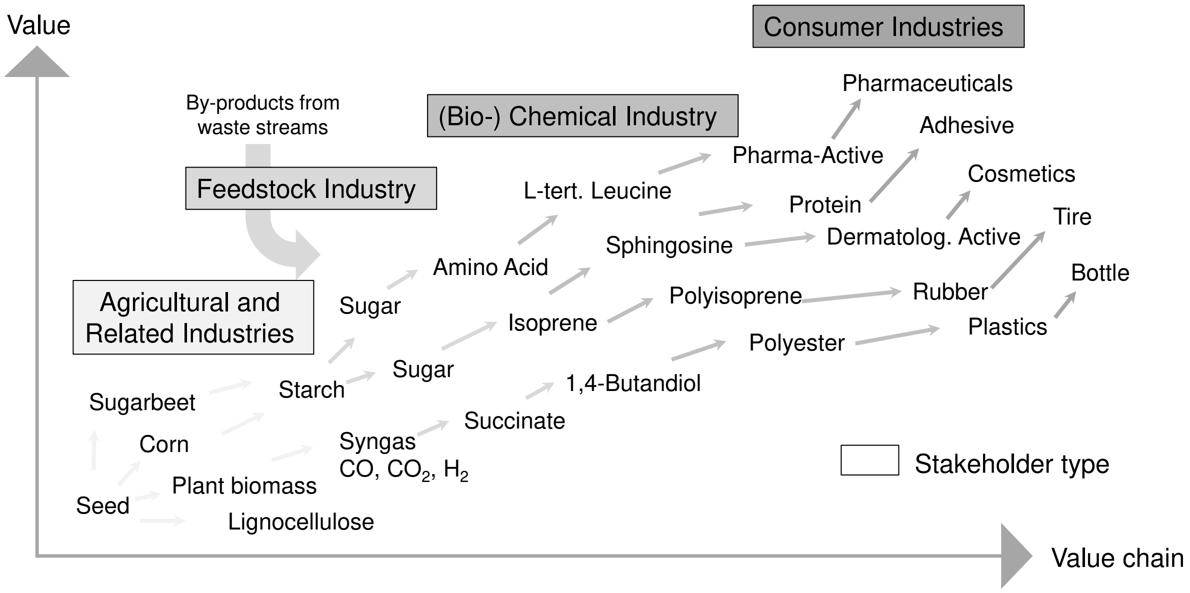

Figure 3.1: Exemplary value chains and industry stakeholders in the bio-based economy. Source: based on Kircher (2012).

3.2.2 Challenges for systemic SOTs and their implementation in value chains

A major challenge impairing the implementation of SOTs is that they are often developed in a specific scientific field or industrial domain, their impact, however, extends beyond industry domains. The challenges companies are facing become evident within the transition from a fossil-based towards a bio-based economy. In this regard, the current dominant design in the chemical and its downstream industries still relies on fossil-based resources. Thus, in this early stage of the development of SOTs different technologies are still emerging and tested within organizations. In this phase, companies need to develop knowledge about new sustainable components and how these components can be integrated (in line with Henderson & Clark, 1990). In contrast to Henderson and Clark (1990), who consider a company's product as a system consisting of different components, we take a value chain spanning perspective reflecting a major part of the technology system.

Analyzing a SOT's environment from a technology system perspective means that one has to consider upstream technologies (e.g., resource / feedstock availability), complementary technologies (e.g., different conversion processes), competing technology systems (e.g., less sustainable fossil-based technologies) and downstream systems (e.g., consumer goods manufacturing) (Geschka, Schauffele, & Zimmer, 2017). In order to achieve an entire system change, we thus need to incorporate all perspectives from the technology system and each actor needs to understand how actors up- and downstream perceive and evaluate the emergence of a new SOT.

The success of systemic SOTs within the bio-based economy relies on the ability of firms to create the necessary infrastructure and value chain connections of hitherto separated value chains rooted in different industrial sectors to distribute the extracted compounds out of the biomass, making this a high-level systemic venture (cf. Figure 3.1). Crop residues or by-products from the food or feedstock industry for example could in a first reaction be treated for high-value compounds that find their way into the (bio-)chemical and finally consumer industry (Carraresi et al., 2018). The by-products from that process, often of lignocellulosic kind, can then be processed into bioethanol that act as input for multiple applications in the plastic industry introducing new product innovations. Biomass that is stripped from its valuable compounds can then even find its final application in the production of energy (Bröring et al., 2020). Here, the underlying technologies such as enzymes catalyzing a reaction in a bioreactor are not radically new, but the value chains are emerging from the integration of previously unconnected actors and sectors, which require the formation of new processes and relationships as well as entirely new business models (Carraresi et al., 2018; Carraresi & Bröring, 2021).

A great challenge lies in the commercialization, as these resources can be used in different industry sectors, whose expectations are not clear to all relevant stakeholders affected by this SOT (Carraresi et al., 2018; Carraresi & Bröring, 2021). The chemical industry, for instance, claims that the pressure to comply with sustainability issues comes from the end customer. The closer the industry is to the end customer, the greater the pressure on the companies, although the pressure is passed on to their upstream suppliers, e.g., the chemical industry (Rigall & Wolters, 2019). This example, again, points to the systemic character of SOTs, since autonomous activities of a single company might not be able to address the current market needs or the grand societal problems such as sustainability transitions (Geels & Schot, 2007; Schaffers & Turkama, 2012). Actors strive to communicate their expectations to other actors within the value chain. In this regard, the consumer industry expects the chemical industry to “think more from the point of view of the consumer” or to “guarantee transparency” or to “rethink business models” (Rigall & Wolters, 2019).

However, industries have different path dependencies and different investment cycles and may invest varying degrees of efforts into sustainability transitions (Bohnsack et al., 2020; Del Río González, 2005). The chemical industry by contrast to the fast moving consumer goods sector is characterized by long-term investments and innovation cycles (Rigall & Wolters, 2019), which also needs to be incorporated by all value chain actors when investing in a SOT.

Research on sustainability assessments, including e.g., life cycle assessments (LCA), claims for the incorporation of various stakeholder lenses, such as workers, consumers, general society, local community and value chain actors, as different stakeholders have different perceptions on sustainability (Falcone et al., 2019). In regard to transition theory and management, the entire regime of innovation and the systemic interactions that occur in the SOT process have to be considered. Transition theory involves all actors from e.g., academia, industry or policy on different levels of perspective, i.e., niche, socio-technical regime or landscape level, when analyzing transition processes (Geels & Schot, 2007). However, a value chain, i.e., cross-industry perspective, in evaluating SOTs is still neglected.

Following from the above mentioned challenges regarding the implementation of SOTs, the success of a R&D process in this context depends on the early integration of different stakeholders (Gasde, Preiss, & Lang-Koetz, 2020). Technology selection is a complex, multi-criteria decision problem for companies, which especially applies for technology-based companies (Ma, Chang, & Hung, 2013). We argue that the systemic character of SOTs adds even another layer of complexity, as co-evolution of different components of the entire, yet unknown, technology system is needed for successful technology selection. Moreover, their market implementation is eventually driven by different stakeholder perceptions and expectations, which have to be aligned. To this end, we address the gap of how emerging SOTs are evaluated across the value chain (from different stakeholders). In order to give an overview of how technologies are usually evaluated and selected, the following section provides an overview of prevailing technology selection criteria.

3.2.3 Technology selection criteria

Technology selection is part of the bigger innovation process starting with technology scanning, selection, adoption until exploitation (Shehabuddeen, Probert, & Phaal, 2006). The selection decision, however, is very challenging as it may involve foresight, dynamics, ambiguity and prudence (Zhao, Kuang, Hao, & Liu, 2020). The technology selection is even more challenging when considering emerging technologies (Rotolo et al., 2017). Following the framework of industrial emergence by Phaal, O'Sullivan, Routley, Ford, and Probert (2011), this paper focusses on technology selection within the science- and technology-dominated emergence phases towards the transition of the applications-dominated emergence phase before a technology’s actual commercialization.

As an initial step of our research, we identified literature that focus on technology selection criteria for SOTs. We found literature on evaluation criteria for specific SOTs, such as biofuels (Kheybari, Rezaie, Naji, & Najafi, 2019) or biotechnology (Kharat, Raut, Kamble, & Kamble, 2016). However, literature is still missing general criteria for SOT selection.

Accordingly, we screened general technology and innovation management literature to collect more evaluation and selection criteria to obtain a starting point for our study.

Table 1 aggregates a summary on existing frameworks for the evaluation and selection of SOTs, R&D projects and technologies in general. This is not an all-encompassing literature review, but provides an overview of various evaluation criteria for different objects of analysis (e.g., R&D projects or SOTs). Literature on evaluation criteria for innovations is not included, as it usually covers a wider scope of evaluation throughout the innovation process, although the majority of research on innovation evaluation focusses on ex-post evaluation and rarely on the early stages of an innovation process, i.e., technology selection (Dziallas & Blind, 2019).

Kheybari et al. (2019) provide a comprehensive literature review of criteria to evaluate technologies converting biomass into biofuels, which can be regarded as SOTs. They provide a technical, economic, environmental and social dimension. They use an analytical hierarchy process to identify different weights for the predefined technology evaluation criteria. According to experts' opinion, the environmental dimension is the most important aspect followed by economic, technical and social aspects (Kheybari et al., 2019). The assessment developed by Zemlickienė and Turskis (2020) to compare the evaluation of information technology and biotechnology, which includes nine dimensions, is even more nuanced and additionally highlights the internal policy of the institution as a criterion for the evaluation of the expediency of technology commercialization. The hierarchy model derived by Hsu, Tzeng, and Shyu (2003) provides evaluation criteria for R&D project selection in the context of government-sponsored projects based upon the experience of different interest groups (e.g., industry, government and academia). They show that there are differences in weights towards individual dimensions (criteria) among different interest groups. Gerpott (2013) provides an overview of generic technology evaluation criteria, which are used by companies within their strategic technology management. Heslop et al. (2001) show that a technology (incl. research team) must reveal a substantive strength in all four dimension - market, technology, commercial and management readiness - to succeed in technology transfer. In Cartalos, Rozakis, and Tsiouki's (2018) framework, the technology evaluation of exploitation projects is conducted by experts with relevant technical background. The commercialization assessment is conducted by business experts in technology or innovation financing. Jain, Martyniuk, Harris, Niemann, and Woldmann (2003) provide a set of six dimensions according to which emerging technologies and their transfer potential can be evaluated.

Table 3.1: Overview of potential technology evaluation and selection criteria.

Dimensions	**Criteria (respective examples)**	**Focus / Reference**
Technical *Economic* *Environmental* *Social*	• Energy efficiency • Incentives and subsidies • Environmental impact • Threaten food security	Technologies converting biomass (Kheybari et al., 2019)
Situation in the market *Value for the consumer* *Financial environment* *Competitive environment* *Technology features* *Competence of developer* *Legal environment* *Inventor profile* *Internal policy of institution*	• Target market share • Predicted offered value • A competitive unit cost • Ability to copy technology • Complexity of technology • Competence of specialized staff • Novelty of technology • Inventor's academic recognition • Compliance with strategy of organization	Information technology and biotechnology (Zemlickienė & Turskis, 2020)
Economic benefits *Social benefits Competitiveness* *Relevance* *Feasibility* *Success rate*	• Market scope of application • Benefits for human life • Innovativeness • Generics or specific • Capability of research team • Intensity of competition	Government-sponsored R&D project selection (Hsu et al., 2003)
Versatility *Locus of invention* *Innovativeness* *Role* *Interdependencies* *IP protection* *Systemicness* *Maturity*	• Platform vs. specific technology • Product vs. process technology • Radical vs. incremental technology • Core vs. supporting technology • Complementing vs. substituting technology • Patented vs. non-disclosure approach • Systems vs. autonomous technology • Technology readiness between 1 to 9	Technology evaluation (Gerpott, 2013)
Market readiness *Technology readiness* *Commercial readiness* *Management readiness*	• The technology has immediate market use • There are no other dominant patents • There is access to venture capital • Management capabilities are available	Technology transfer evaluation (Heslop et al., 2001)
Technology-innovation *Market opportunities* *Exploitation team*	• Technology maturity • Competitive advantage • Necessary business skills	Technology transfer evaluation (Cartalos et al., 2018)
Technical *Process* *Economic* *Market* *Perception* *Regulatory / Policy*	• Technical feasibility • Implementation requirements • Capital requirements • Market demand • Risk aversion • Incentives	Emerging technology and technology transfer evaluation (Jain et al., 2003)

Remark: The references are listed from top to bottom from more evaluation criteria for particular SOTs to more general technology or R&D project evaluation criteria.

To the best of our knowledge, there are no studies on technology selection criteria from a systemic perspective necessary to identify differences along a value chain. Thus, the criteria shown in Table 3.1 are our starting point to derive holistic criteria for the selection of SOTs from a value chain spanning perspective. Accordingly, this paper applies an exploratory mixed-method research design. In contrast to previous literature, our aim is not to derive an assessment tool for technology selection or the evaluation of transfer potential of selected technologies. We rather strive to gain insight into the currently poorly understood perceptions of companies with respect to technology selection of SOTs along the value chain, in order to incorporate the systemic character of SOTs and to derive recommendations to foster the implementation of SOTs in the context of sustainability transition. Accordingly, depending on the effect a SOT has on different stakeholders (degree of which it has a value chain spanning character, i.e., requires interfaces, such as feedstock and refinery process, to be complementary), more specific recommendations can be given. Thus, we seek to identify specific criteria to assess SOTs derived from this present study in order to add to prevailing assessment tools and expand these to cover the particularities of sustainability transitions.

3.3 Research design: group concept mapping

3.3.1 Overall study approach

We follow the research design of group concept mapping (GCM) which is a mixed-method approach. This methodology has been used in various contexts, such as entrepreneurship (Cloutier, 2017), technology transfer (Borge & Bröring, 2020), public health (Blackstone et al., 2017) or energy efficiency (Schröter, Coryn, Cullen, Robertson, & Alyami, 2012) to integrate input from multiple stakeholders with different interests and expertise from a bottom-up perspective (Trochim, 1989). GCM enables the presentation of concept maps that visualize the composite thinking of a group in relation to the research problem under consideration (Trochim, 1989). In contrast to the Delphi technique, which also relies on the knowledge of selected experts by letting them answer structured questionnaires, GCM is focused on one particular question which is formulated as an open sentence provoking the generation of manifold ideas. In this section, we explain the basic steps of GCM (cf. Figure 3.2) and introduce the chosen case of the bio-based economy (cf. Figure 3.1).

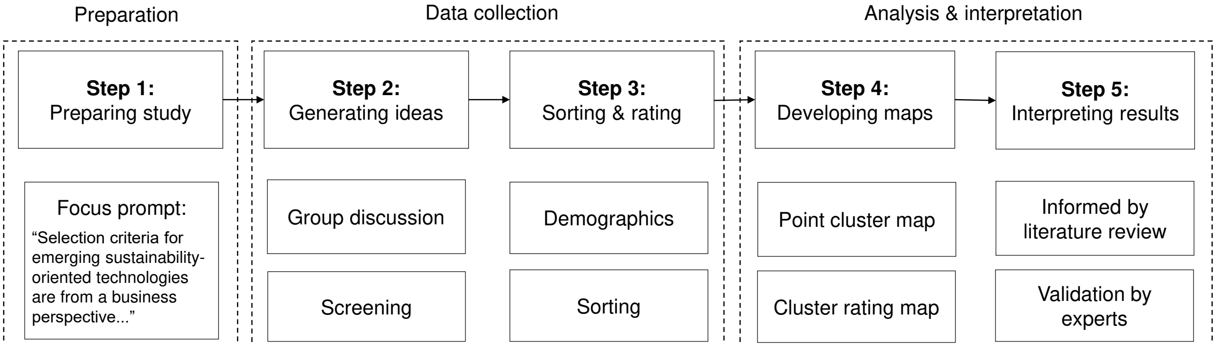

Figure 3.2: Steps of the group concept mapping study. Source: based upon Kane and Trochim (2007).

3.3.2 Preparation

In step 1 (cf. Figure 3.2), the preparation phase, the so called “focus prompt” is defined. It addresses business (companies) and is an open sentence which should provoke ideas during the group discussion. Our focus prompt *“Selection criteria for emerging sustainability-oriented technologies are from a business perspective...”* has to be concluded by the participating stakeholders. In the context of this study, we are interested in the perspectives of different stakeholders concerning SOT evaluation along the value chain eventually providing a value chain spanning perspective. Therefore, as a case example we chose the bio-based economy and their underlying value chains.

Initially, we identified five crucial stakeholder groups representing the business perspective of value chains of the bio-based economy. It starts with (1) agricultural and related industries as suppliers of organic raw materials for e.g., the (2) feedstock industry which carries out the first transformation of the raw material into its individual components. Together with recycled substances from waste streams and other valuable by-products, these components are fed into the supplying value chain of the (3) (bio-) chemical industry. This is where the high-tech and highly specialized chemical and biotechnology firms substitute their fossil raw material in whole or in part with the new bio-based alternative for the production of biochemicals, biopolymers and even high-value pharmaceutical components. Finally, the (4) consumer industries process the various bio-based chemicals and other components into final demand goods for the consumer. In order to complement the relevant manufacturing industry perspectives of the bio-based economy, we included representatives of (5) consultancies and industry networks. They form the intersection between developers of SOTs and adopters of SOTs and therefore represent valuable all-rounders with a deep and universal knowledge of international markets, trends and developments, a technology’s fit to existing business and customer requirements. It should be noted that based upon this value chain we selected relevant experts. Due to the difficulties in differentiating between “agricultural and related industries” and “feedstock industry”, for our following analysis we decided to summarize both stakeholder types under the overall stakeholder type “agricultural and feedstock industry”.

Except being part of the value chains of the bio-based economy (cf. Figure 3.1), a precondition for selecting relevant experts for our study was that they are familiar with R&D and innovation management, thus being familiar with technology evaluation and selection. Participants were mainly drawn from different innovation or industry networks (e.g., CLIB or DECHEMA), which were complemented by the authors’ own network within the bio-based economy. Further contacts were selected via Pitchbook, LinkedIn and research on companies’ websites. In total, we contacted 182 experts directly via Email or LinkedIn message and approached indirectly an uncountable number of experts via LinkedIn posts and newsletters through various industry networks. All stakeholders being interested in taking part in sorting and rating process (step 3) had to send us an email and we then sent them an online link to the software. Accordingly, as we collected information about their profile beforehand, we assure that they fulfilled our requirements and were able to contribute to the study. All experts except one located in Switzerland, work for organizations located in Germany.

3.3.3 Data collection

Step 2 and 3, the data collection, consists of a qualitative and a quantitative step. In step 2, the qualitative part, we conducted the group discussion around the predefined focus prompt to generate statements on the research problem. From the twelve predefined participants, one person dropped out during the online discussion and did not contribute to the discussion. Thus, eleven experts (participants) are listed in Table 3.2. The size of the sample is adequate, as it falls within the recommended range of 10–20 stakeholders, who should participate in step 2 of the GCM (Trochim, 1989).

Table 3.2: Participants contributing to the online group discussion.

Stakeholders’ industry origin	Number of stakeholders	Inclusion criteria
Agricultural and feedstock industry	3	Must be familiar with SOT and technology evaluation (participants stem from R&D or innovation management)
(Bio)-chemical industry	4	
Consumer industries	1	
Consultancies and industry networks	3	
Total	11	

As a preparation for the participants we sent out a short presentation beforehand, which we also presented in the beginning of the group discussion to introduce the topic, our understanding of the different dimensions of SOTs, some examples and the focus prompt which was the starting point of the discussion. The content of the discussion was eventually driven by the participants’ active engagement. We, as the researchers, were only the moderators and raised a few trigger questions in situations, when the participants’ engagement has declined. Questions encompassed aspects, such as how evaluation criteria for SOTs may differ from evaluation criteria for conventional technologies or the role of exploration vs. exploitation (Cillo, Petruzzelli, Ardito, & Del Giudice, 2019) while selecting SOTs. The workshop including introduction and closing took 3 hours. The actual group discussion took 1.5 hours, which has led to a transcript comprising 24 pages. This transcript was screened and coded in MAXQDA by two independent researchers to derive the holistic set of statements (perceptions) of which selection criteria for SOTs might exist. Deductive codes were based upon literature review (cf. section 2.2); new codes were inductively drawn from the text.

In step 3, the quantitative part, these statements had to be sorted and rated by stakeholders within the online software g*roupwisdom.* Before starting the actual sorting and rating process all participants had to read and confirm an information text on our study purpose and understanding of SOTs (cf. Figure A1). Thus, all participants were aware that this study mainly focusses on the ecological dimension of SOTs and particularly addresses the challenges associated with SOTs requiring different industries to change their processes to sensitize participants to the fact that the perspective of different stakeholders matters. Additionally, participants had to answer five demographic questions (cf. Table A3) regarding its stakeholder type, company size, understanding of SOTs, level of prior knowledge of SOTs and the company's sustainability orientation. The variable 'stakeholder type' is the most relevant one for our further analysis. The remaining variables allow for a more detailed description of our sample (cf. Table A4 to A6). Sorting is the process by which participants individually group the ideas into piles that make sense to them. Participants were asked to group the ideas into categories based on similarity or connection, not value. Value contributions are made during the rating activity according to the predefined scale "relevancy". Figures A2 and A3 in the appendix show the instruction to the sorting and rating process. For the sorting process, participants were also asked to provide labels for the generated piles. The sorting and rating task could be performed individually, that is why some participants either dropped out after the one or the other activity. Accordingly, the number of participants varies in between both activities. In order to include participants' sorting activity in our analysis, 75% or more of the statements had to be sorted into piles and cluster labels had to be provided (as suggested by groupwisdom, 2021). In total, 58 participants have started the sorting process, whereby 45 finished the sorting in line with this 75% rule. After manual screening of each participant's individual sorting, we included 40 participants according to our additional requirements. We excluded, for instance, data that did not contain cluster labels or revealed an obvious sorting according to relevancy, which should be avoided in the sorting, as this is the aim of the rating process. Except for one participant included in our results, who only sorted 47 out of 59 statements, all participants sorted the entire set of 59 statements. The rating task was started by 51 stakeholders and finished by 49, which were all included in the analysis.[3] One stakeholder represents a distinct company or strategic business unit within an organization. The detailed breakdown of the participating stakeholders is

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[3] It should be noted that one out of these 49 participants only rated 58 out of 59 statements.

presented in Table 3.3. More information on the participating stakeholders can be found in the appendix in Tables A2 to A4.

Table 3.3: Profiles of participants.

	Sorting statements (n=40)		Rating statements according to relevancy (n=49)	
Stakeholders' industry origin	n	%	n	%
Agricultural and feedstock industry	12	30.0	14	29.0
(Bio)-chemical industry	12	25.0	14	29.0
Consumer industries	6	15.0	8	16.0
Consultancies and industry networks	10	25.0	13	26.0

3.3.4 Data analysis and interpretation of maps

In steps 4 to 5, the data were analyzed and interpreted. In step 4, the responses from stakeholders completing the sorting and rating served as input for the creation of visual maps. Therefore, first, based on each participant's sorting, *binary similarity matrices* are generated. The matrix has as many rows and columns as there are statements. The individual matrix represents how each participant perceives the relationship between statements (Kane & Trochim, 2007). The cells indicate whether a stakeholder has put two statements on one pile, i.e., a "1" is entered if the pair of row and column was sorted together, and a "0" if not. Second, the individual matrices are summed up across all stakeholders to create an *aggregated similarity matrix* with numbers in each cell representing how many participants put that pair of statements together in the same pile. This aggregated similarity matrix serves as input for the *multidimensional scaling (MDS) analysis* (Kane & Trochim, 2007). MDS transfers the aggregated similarity matrix towards a basic map in two-dimensional (x, y) space, where each statement is a point on the map (Kane & Trochim, 2007). Statements that are often sorted together are placed more closely to each other on the map. The two-dimensional point map serves as input for the *hierarchical cluster analysis* with the aim to divide the map into groups of statements that reflect similar concepts. For this purpose, the Euclidean distance between the coordinates from the multidimensional scaling by using the Ward´s algorithm are calculated (Kane & Trochim, 2007). The point map in two-dimensional space is fixed, the cluster analysis, however, represents a more flexible process that depends on how the results are interpreted (Borge & Bröring, 2020; Kane & Trochim, 2007). The ratings collected from the Likert-scale responses are then added to the concept maps in order to show the differences in relative relevancy for each cluster. Additionally, pattern matches are created to show the perceived relative relevancy across stakeholder groups along the value chain with respect to the different clusters. This, accordingly, reflects the coherence between the stakeholder groups.

In step 5, the maps are interpreted and discussed in light of the initial literature review and a second stakeholder workshop with a set of six experts drawn from the stakeholders who have participated in the sorting phase. The goal of this workshop was to validate the clusters and to revise cluster labels or cluster boundaries if necessary.

3.4 Results

3.4.1 Selection criteria for SOTs from a value chain spanning perspective

We derived 59 selection criteria for SOTs from a value chain spanning perspective allocated to 11 clusters (see Table 3.4). Initially, we started with 15 clusters based on MDS and, subsequently, decreased the number of clusters to compare different cluster solutions. In each step we checked for content coherence and meaningfulness of the cluster solution. Second, these cluster solutions were discussed in a stakeholder workshop with a set of six experts to confirm this solution. A brief description of the types of ideas contained in each cluster is explained below:

- *Value of sustainability*, i.e., the impact of sustainability on the company's listing and the ease of capital procurement.
- *External communication and customer orientation,* i.e., the public acceptance of technology and the sustainable aspects of the technology that are communicated to customers and other stakeholders.
- *Future competitiveness,* i.e., the possibility to create new market potentials and achieve a competitive advantage.
- *Economic viability*, i.e., the economic profitability and the avoidance of switching costs as well as the valorization of by-products with the technology.
- *Corporate entrepreneurship*, i.e., the manager's risk tolerance and the necessity to change the business model
- *Technical feasibility*, i.e., the technology's scalability and proximity to the company's core business as well as the securing of an equivalent quality to a conventional alternative.
- *Ease and controllability of technology integration*, i.e., the simplicity of integrating the technology in existing infrastructures and the internal validation and controllability of the technology.
- *Presence of needed capabilities*, i.e., the presence of interdisciplinary human resources and employees that are able to understand the new technology.
- *Access to networks and open innovation*, i.e., the possibility to cooperate with start-ups and other networks.
- *Industry supporting conditions*, i.e., the presence of specific standards and financial support for companies.

- *Compliance with political and legal frameworks*, i.e., the presence of political incentives and requirements to use SOTs.

Table 3.4 includes the average relevance rating for all selection criteria sorted by clusters across all stakeholders as well as according to the four distinct stakeholder groups. The last column contains the coherence between the four stakeholder groups, which is here reflected by the variance between the average ratings of the four stakeholder groups. That means the higher the value (variance), the lower the coherence.

Table 3.4: List of statements with average relevance rating grouped by clusters.

Cluster	Statement (Focus prompt: "Selection criteria for emerging sustainability-oriented technologies are from a business perspective...")	Average relevance across all stakeholders	Relevance for agricultural and feedstock industry	Relevance for (bio)-chemical industry	Relevance for consumer industries	Relevance for consultancy and networks	Coherence
Value of sustainability		**3.66**	**3.63**	**3.77**	**3.66**	**3.60**	**0.006**
6	the increasing importance of sustainability rankings for companies.	3.67	3.86	4.00	3.50	3.23	0.12
7	the increasing importance of "sustainability" for groups of investors, which possibly facilitates capital procurement (e.g., Environment, Social, Governance (ESG) criteria).	3.65	3.71	3.50	3.50	3.85	0.03
25	the possibility to get a certification for the sustainability of the technology.	3.59	3.14	3.57	3.88	3.92	0.13
42	the confirmation of sustainability for example via a life cycle assessment.	3.73	3.79	4.00	3.75	3.38	0.07
External communication and customer orientation		**4.11**	**4.13**	**4.11**	**4.15**	**4.07**	**0.001**
1	whether the technology's sustainability can be communicated and is visible for the customer.	4.16	4.21	4.29	4.25	3.92	0.03
11	the consumer acceptance for the new technology.	4.27	4.21	4.50	4.50	3.92	0.08
18	the sustainability as such, that is added as an additional differentiating characteristic.	3.88	3.57	4.00	3.88	4.08	0.05
19	the end consumers' demand for sustainable products.	4.35	4.50	4.36	4.13	4.31	0.02
22	the possibility to generate a positive image for the company.	4.27	4.29	4.21	4.50	4.15	0.02
28	the possibility to create new sustainability-oriented customer experiences.	3.84	3.79	3.79	3.75	4.00	0.01
29	the possibility to achieve a sustainability-oriented positioning of existing products, processes and/or services (sustainability story).	4.12	4.36	3.86	4.13	4.15	0.04
55	the public image that a technology has.	3.88	4.00	3.93	3.63	3.85	0.03
56	the compliance to existing / familiar customer expectations or customer experiences.	4.24	4.21	4.07	4.63	4.23	0.06
Future competitiveness		**4.24**	**4.23**	**4.30**	**4.15**	**4.26**	**0.004**
12	the true sustainability compared to relevant alternatives.	4.06	3.79	4.07	4.13	4.31	0.05
20	the possibility to develop new market potentials.	4.35	4.36	4.43	4.13	4.38	0.02
52	the potential to achieve a competitive advantage.	4.67	4.79	4.71	4.50	4.62	0.02
53	the potential to create a new product with new properties.	3.86	3.79	4.07	3.88	3.69	0.03
58	the existence of a secure market for nascent products, processes and/or services.	4.29	4.43	4.21	4.13	4.31	0.02

Cluster	Statement (Focus prompt: "Selection criteria for emerging sustainability-oriented technologies are from a business perspective...")	Average relevance across all stakeholders	Relevance for agricultural and feedstock industry	Relevance for (bio)-chemical industry	Relevance for consumer industries	Relevance for consultancy and networks	Coherence
Economic viability		**3.97**	**4.04**	**3.73**	**3.93**	**4.18**	**0.037**
4	their economic profitability.	4.63	4.71	4.64	4.50	4.62	0.01
21	the possibility to valorize by-products with the technology.	3.39	3.79	3.07	3.13	3.46	0.11
27	the possibility to substitute existing, less sustainable technologies.	3.73	3.71	3.43	3.75	4.08	0.07
37	the compatibility of the new technology with existing manufacturing processes of the customer (no switching costs).	3.96	3.77	3.71	4.13	4.31	0.08
41	the technology's economic sustainability regardless of subsidies.	4.14	4.21	3.79	4.13	4.46	0.08
Corporate entrepreneurship		**3.58**	**3.54**	**3.71**	**3.25**	**3.67**	**0.044**
15	the risk tolerance of entrepreneurs.	3.69	3.57	4.07	3.00	3.85	0.21
17	the necessity to change the business model if the existing technology is not competitive anymore.	3.90	3.57	3.86	3.50	4.54	0.22
30	the possibility to generate intellectual property (patents).	3.35	3.36	3.86	2.88	3.08	0.18
43	the access to regionally produced resources.	3.37	3.64	3.07	3.63	3.23	0.08
Technical feasibility		**3.98**	**3.93**	**3.96**	**3.98**	**4.04**	**0.002**
3	the influence on the company's existing processes or business units through the new technology.	3.84	4.21	3.71	3.63	3.69	0.07
5	their proximity to the core business.	3.78	3.64	3.64	4.13	3.85	0.05
10	the availability of bio-based resources.	3.80	3.64	4.21	3.75	3.54	0.09
13	the technology's scalability.	4.20	4.14	4.29	3.75	4.46	0.09
14	the securing of an equivalent quality as a conventional alternative.	4.41	4.07	4.57	4.38	4.62	0.06
26	the possibility to increase efficiency with existing processes and infrastructure.	4.08	4.29	3.57	4.38	4.23	0.14
36	the innovation cycle's length for the new technology.	3.53	3.21	3.64	3.38	3.85	0.08
45	the fit with the product and production-related corporate strategy.	4.18	4.21	4.07	4.50	4.08	0.04
Ease and controllability of technology integration		**3.81**	**3.92**	**3.61**	**3.91**	**3.86**	**0.021**
24	the possibility to test the new, sustainable technology in the own company.	3.53	3.79	3.21	3.75	3.46	0.07
38	the internal validation and controllability of the technology.	3.98	3.79	3.86	3.88	4.38	0.08
39	the simplicity of integrating the technology into existing value chains.	4.12	4.14	3.86	4.63	4.08	0.10

Cluster	Statement (Focus prompt: "Selection criteria for emerging sustainability-oriented technologies are from a business perspective...")	Average relevance across all stakeholders	Relevance for agricultural and feedstock industry	Relevance for (bio)-chemical industry	Relevance for consumer industries	Relevance for consultancy and networks	Coherence
40	the simplicity of integrating the technology into the existing infrastructure of the company.	4.10	4.14	3.64	4.63	4.23	0.16
44	the new technology's maturity level.	3.73	4.00	3.43	4.00	3.62	0.08
46	that preferably all risks that are linked to the technology were carefully considered.	4.00	3.86	4.14	4.00	4.00	0.01
54	the technology's potential to cause a systemic change of value chains beyond the company's boundaries.	3.22	3.71	3.14	2.50	3.23	0.25
Presence of needed capabilities		**3.54**	**3.75**	**3.25**	**3.25**	**3.81**	**0.094**
23	the possibility to test the new, sustainable technology in external technology centers.	2.94	3.21	2.43	2.50	3.46	0.27
47	that own employees are able to understand and evaluate the technology.	3.92	4.14	3.57	3.63	4.23	0.12
51	the presence of interdisciplinary human resources and knowledge in the company.	3.82	4.00	3.79	3.63	3.77	0.02
57	the existence of corporate structures that enable cross-functional activities.	3.49	3.64	3.21	3.25	3.77	0.08
Access to networks and open innovation		**3.04**	**2.73**	**3.11**	**2.83**	**3.43**	**0.100**
31	the possibility of access to new networks.	3.02	2.71	2.86	3.25	3.38	0.10
32	the possibility for knowledge exchange with start-ups.	2.78	2.64	3.14	2.25	2.85	0.14
33	the possibility for knowledge exchange with external actors in existing networks.	3.37	3.07	3.00	3.38	4.08	0.24
34	the possibility for collaboration with start-ups.	2.67	2.36	3.00	2.25	2.92	0.15
35	the possibility for collaboration with external actors in existing networks.	3.37	2.86	3.57	3.00	3.92	0.25
Industry supporting conditions		**3.29**	**3.05**	**3.31**	**2.71**	**3.87**	**0.241**
8	the availability of support possibilities for small and medium sized enterprises.	3.12	2.71	3.36	2.13	3.92	0.61
9	the availability of capital for high-risk investments.	3.55	3.21	3.86	2.63	4.15	0.47
50	the presence of industry standards for the application of the new technology (e.g., DIN norms).	3.18	3.21	2.71	3.38	3.54	0.13
Compliance with political and legal frameworks		**3.96**	**4.11**	**3.94**	**3.58**	**4.06**	**0.059**
2	whether workers' rights are complied with.	4.04	4.36	4.07	4.13	3.62	0.10
16	the planning reliability for the future existence of political framework conditions.	4.04	4.43	3.79	3.38	4.31	0.24

Cluster	Statement (Focus prompt: "Selection criteria for emerging sustainability-oriented technologies are from a business perspective...")	Average relevance across all stakeholders	Relevance for agricultural and feedstock industry	Relevance for (bio)-chemical industry	Relevance for consumer industries	Relevance for consultancy and networks	Coherence
48	the presence of legal framework conditions for authorization and application which were set by policy makers.	4.06	4.21	4.07	3.25	4.38	0.25
49	the presence of political incentives.	3.39	3.21	3.64	3.00	3.54	0.09
59	the current existence of legal requirements that must be complied with.	4.29	4.36	4.14	4.13	4.46	0.03

Figure 3.3, showing the point cluster map, is the graphical representation of the MDS. The MDS yields a stress value of 0.2578, which falls in the range of stress values between 0.205 and 0.365 reported in other concept mapping projects (Trochim, 1993). Thus, the map is a reliable representation of the similarity matrices and reflects how each cluster or single criterion is related to each other. Criteria or clusters that are close to each other were frequently sorted into one pile by the participants during the sorting process. For instance, the clusters *value of sustainability* and *external communication and customer orientation* are highly related to each other. That was also confirmed within the second stakeholder workshop in step 5, since some participants were arguing for merging both clusters. The same applies, for example, for the two closely located clusters *industry supporting conditions* and *compliance with political and legal frameworks.* However, we decided to consider them separately as they contain distinct perceptions. For example, criteria belonging to *future competitiveness* or *access to networks and open innovation* were only rarely sorted together, that is why they are located quite distant from each other. Interestingly, the cluster *corporate entrepreneurship* is located in the center of the map, which means that all criteria in this cluster are somehow related to other clusters.

The cluster labels are inspired by the participants' suggestions in the sorting phase. They were, however, manually revised so that they comprehensively describe the content of each cluster. Also, in line with Kane and Trochim's (2007) suggestion, after the hierarchical cluster analysis some statements were manually shifted from one neighboring cluster to another, as the clusters' content appeared to be more coherent afterwards. More precisely, we shifted statements 6 and 42 from *external communication and customer orientation* to *value of sustainability*. Additionally, we shifted statement 12 from *external communication and customer orientation* to *future competitiveness*. Eventually, we shifted statement 2 from *industry supporting conditions* to *compliance with political and legal frameworks* and statement 54 from *corporate entrepreneurship* to *ease and controllability of technology integration*. All in all, the final cluster solution has been validated by the experts from the second stakeholder workshop.

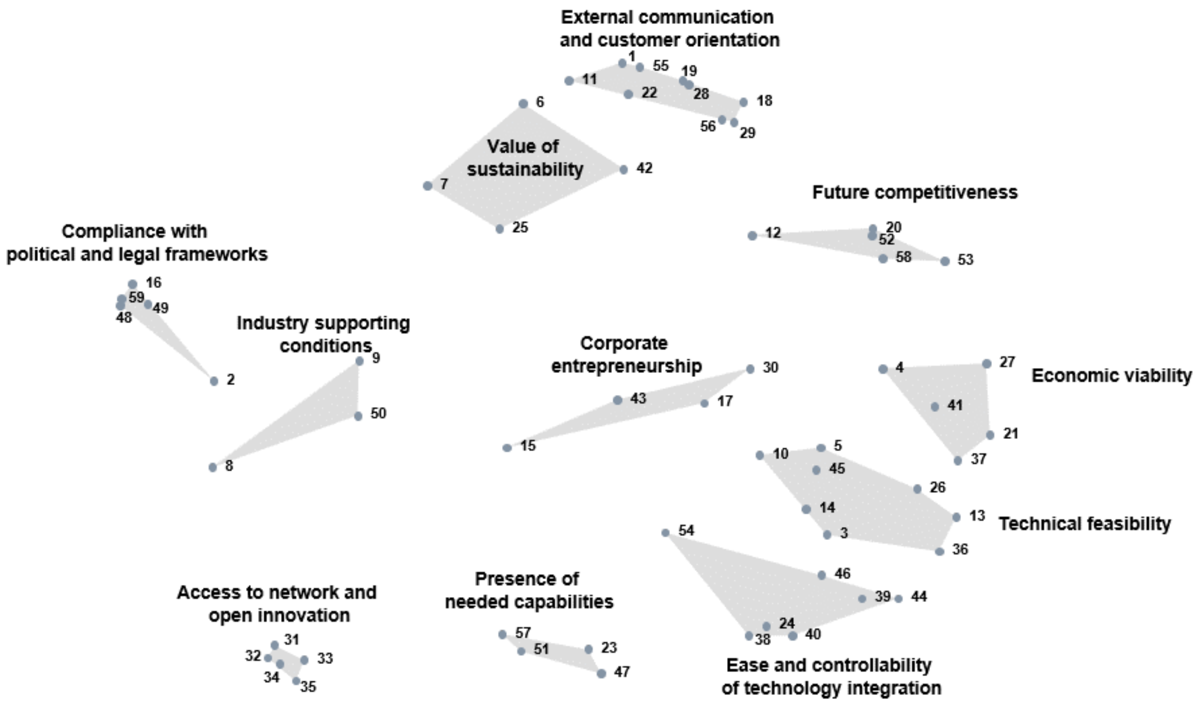

Figure 3.3: Point cluster map for the 11 clusters with their respective labels.

3.4.2 Perceived relative relevancy of selection criteria

Besides the sorting of criteria, participants were asked to rate each selection criteria according to its relevancy from their individual business perspective. Figure 3.4 presents the point cluster map with the average rating of relevancy across all stakeholders. For example, it shows that criteria referring to *future competitiveness* and *external communication and customer orientation* are on average highly relevant. Contrary, criteria referring to the cluster *access to networks and open innovation* are least relevant.

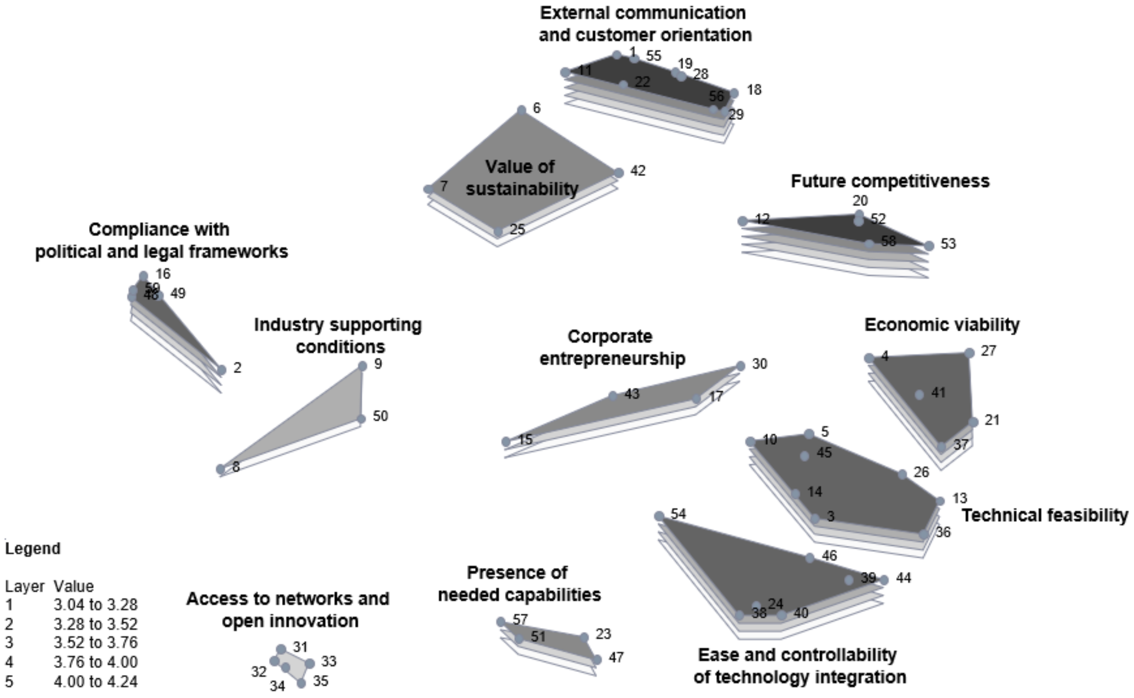

Figure 3.4: Cluster rating map with the average ratings of relevancy.

Remark: ratings are based on a 5-point Likert scale.

Figure 3.5 illustrates the comparison between the different stakeholder types along the value chain of the bio-based economy while focusing on the three manufacturer perspectives from the agricultural and feedstock, (bio-)chemical and consumer industries. We excluded the stakeholder group of networks and consultancies in Figure 3.5, as for this purpose they cannot be directly allocated to a certain position in the value chain. The pattern matches in Figure 3.5 are based upon the mean value across all criteria within a cluster aggregated on stakeholder group level. For the agricultural and feedstock industry the *compliance with political and legal frameworks* and the *presence of needed competencies* are more relevant than for the other industries in the value chain. In contrast to this, *access to networks and open innovations* are perceived as least relevant by the agricultural and feedstock industry when selecting emerging SOTs. On the one hand, the (bio)-chemical industry perceives, in comparison to the other industries in the value chain, *access to network and open innovation, industry supporting conditions* and *corporate entrepreneurship* as more relevant. On the other hand, although still perceived as relevant, it rates the *ease and controllability of technology integration* as well as the *economic viability* as less relevant than the other stakeholders did. For the consumer industry, the *ease and controllability of technology integration* is perceived as a relevant cluster. Interestingly, *compliance with political and legal frameworks* and *industry supporting conditions* are rated as considerably less relevant in comparison to the other stakeholder types.

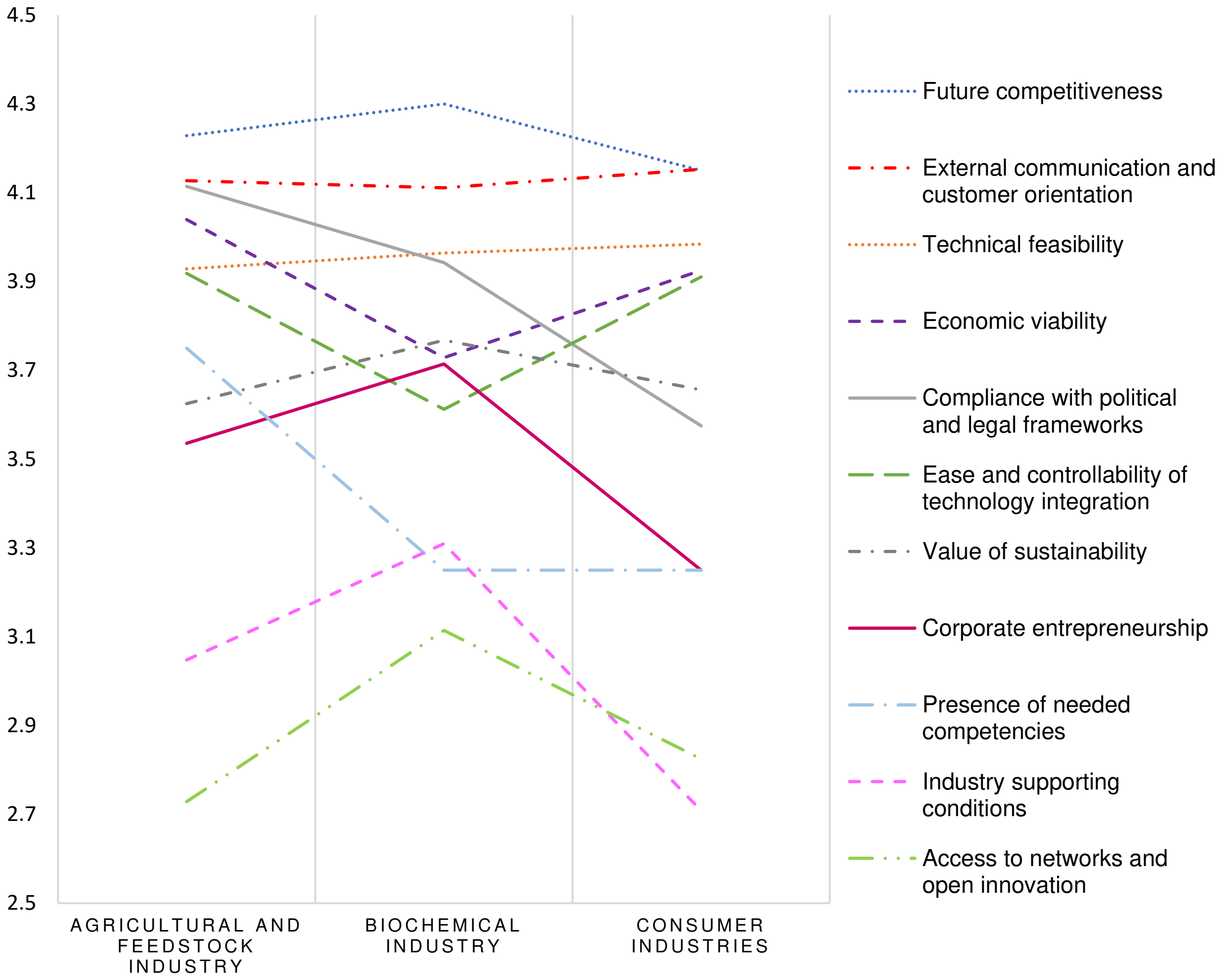

Figure 3.5: Pattern matches - average relevancy along the value chain of the bio-based economy.

Remark: The pattern matches were developed by first computing the statement averages across each stakeholder group (i.e., agricultural and feedstock, (bio)-chemical and consumer industries) and then computing the averages for the respective clusters.

3.5 Discussion

This study identifies 59 selection criteria for SOTs being sorted into 11 clusters. To reach a higher level of abstraction of clusters and hence, to summarize our results, we arranged the technology selection criteria for SOTs according to four overarching dimensions, informed by existing literature in the field of technology selection. Figure 3.6 provides a graphical representation of these overarching dimensions. (1) *market environment and viability* which refers to all external factors concerning customers, competitors and investors, (2) *corporate strategy and technology integration* which encompasses the technology characteristics itself and its internal integration, (3) *capabilities and knowledge exchange* encompassing internal and access to external knowledge and (4) *institutional and regulatory frames* which cannot be easily influenced by the company. The market dimension (1) can be related to market pull factors described by Horbach, Rammer, and Rennings (2012) as determinants for eco-innovations. The technology integration dimension (2) can be related to technology push and firm specific factors (Horbach et al., 2012). The capabilities dimension (3) can be underpinned by literature from the strategic management view (e.g., resource-based view or dynamic capability perspective) (Barney, 1991; Dangelico, Pujari, & Pontrandolfo, 2017; Teece, Pisano, & Shuen, 1997). Eventually, the regulatory dimension (4) is also embedded in transition theory and management constituting a part of the socio-technical landscape being difficult to influence by single companies and the regime which holds certain rules for the industry or individual company (Geels & Schot, 2007).

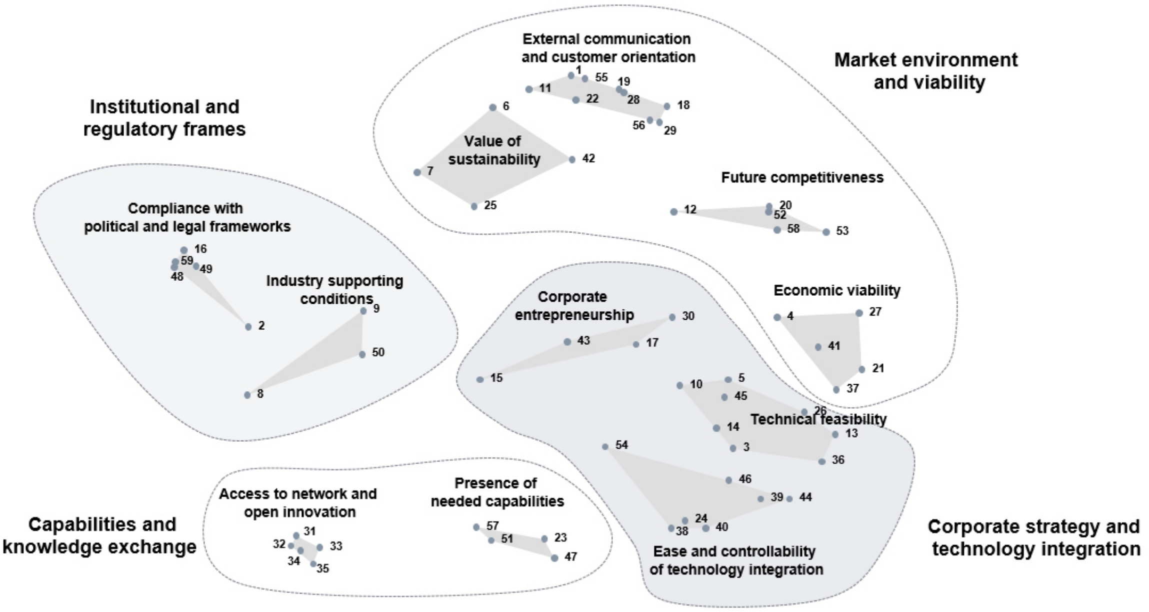

Figure 3.6: Four overarching dimensions for the evaluation of sustainability-oriented technologies.

In the following, we will discuss our results from three perspectives, (1) the cluster solution, (2) the different stakeholder perspectives and (3) the role of selection criteria for various types of innovation. First, we will discuss our results with a focus on the cluster solutions allocated to the different overarching dimensions. Within the (1) *market environment and viability* dimension as well as in total, the cluster *external communication and customer orientation* is the largest cluster containing most individual criteria, which corresponds to previous studies (Aristodemou, Tietze, & Shaw, 2020). The included statements 1 (*whether the technology's sustainability can be communicated and is visible for the customer*) or 56 (*the compliance to existing / familiar customer expectations or customer experiences*) are for instance criteria which are especially challenging to fulfill in the context of SOTs resulting from systemic innovations, as they require many interactions between the stakeholders. The customer's concern are criteria which are especially mentioned in the context of SOTs (Visser, Jongen, &

Zwetsloot, 2008; Zemlickienė & Turskis, 2020). Similarly, the cluster *future competitiveness* includes criteria which are in line with previous literature (e.g., Cartalos et al., 2018; Kassem, Al-Haddad, Komljenovic, & Schiffauerova, 2016). Compared to existing literature on technology selection criteria, the cluster *value of sustainability* contains new criteria, which are particularly relevant for the evaluation of SOTs. For instance, statement 7 (*the increasing importance of "sustainability" for groups of investors, which possibly facilitates capital procurement, e.g., Environment, Social, Governance (ESG) criteria*) has not been described in literature in the context of the evaluation of technologies, although this becomes increasingly relevant in business (Clementino & Perkins, 2021). Regarding the *value of sustainability*, in contrast to the often observed phenomenon of greenwashing (Torelli, Balluchi, & Lazzini, 2020), our study shows that it is important for stakeholders throughout the value chain that there is a proof of a true sustainability confirmed e.g., by LCAs. Within the cluster *economic viability,* statement 14 (the technology's economic sustainability regardless of subsidies) builds the heart of the cluster. That should be highlighted, since it is a criterion which has not been specifically mentioned within existing literature, although it is also linked to the expectation of stakeholders that all risks including unreliable political frameworks (cf. statement 46) or the existence of a secure market (cf. statement 58) associated with the new technology are carefully considered (Del Río González, 2005). However, it should be noticed that the relevancy of economic viability might negatively affect sustainability transition, as new emerging technologies are usually less profitable than established often fossil-based technologies (Bohnsack et al., 2014). Our results support prior research that *external communication and customer orientation* are highly relevant throughout the value chain, not only for these stakeholders which are directly in touch with the end consumer (i.e., consumer industry). The high relevance of *external communication and customer orientation* and f*uture competitiveness* is in line with literature, since SOTs have to diffuse in society to unfold their potential (Boons & Lüdeke-Freund, 2013; Jay & Gerard, 2015). In general, the role of market demand is also discussed in literature as a driver for eco-innovations (Horbach et al., 2012).

In dimension (2) *corporate strategy and technology integration*, especially within the cluster *corporate entrepreneurship,* statement 15 (*the risk tolerance of entrepreneurs*) can be related to the sensitivity of managers for sustainability (Hansen, Grosse-Dunker, & Reichwald, 2009). As the cluster lies in the center of the map, which means it is somehow related to all other clusters, it appears to be at the core when selecting emerging SOTs. The cluster t*echnical feasibility* refers to selection criteria, which are in line with previous literature (e.g. Kassem et al., 2016; Visser et al., 2008; Zemlickienė & Turskis, 2020). The cluster *ease and controllability* *of technology integration* is an important group of selection criteria in the context of systemic SOTs, as criteria in this group also refer to the change of existing processes or value chains going along with the technology. Criteria in this cluster can be also validated by previous findings in literature (e.g. Del Río González, 2005; Visser et al., 2008).

In dimension (3) *capabilities and knowledge exchange,* criteria referring to the cluster *presence of needed competencies* are coherent with previous studies as well, which showed that SOTs require, for instance, a higher level of organizational capabilities than traditional innovations as there is a special necessity for inter- and intra-organizational collaborations (Messeni Petruzzelli, Maria Dangelico, Rotolo, & Albino, 2011). Additionally, internal competencies are essential to assimilate the technical knowledge from outside of the company (Del Río González, 2005), which might be also considered as a prerequisite for being able to evaluate and select a SOT. The cluster *access to networks and open innovation* reveals a few new criteria playing a role in the evaluation of emerging SOTs. The necessity to collaborate with external parties when developing SOTs is known (Messeni Petruzzelli et al., 2011), however, our study reveals that the possibility to access new networks or exchange with start-ups created by the new technology also play a role in the selection process of a SOT. That is another perspective, since not the development of the new technology itself is meant with these criteria, but rather the opportunities that may arise for the company in the future through the selection of a SOT. It might be also relevant that through the access to SOTs, companies gain attractiveness for start-ups. Start-ups play a crucial role in sustainability transitions while exploiting technological knowledge (Leendertse, Rijnsoever, & Eveleens, 2021). Leendertse et al. (2021) found that depending on the type of technology, i.e., physical vs. digital, start-ups are introducing to the market the business performance might vary. Accordingly, technologies having a higher potential climate performance reveal a lower business performance and vice versa. That should be also beard in mind when selecting SOTs, as economic viability is one of the most relevant criteria for selecting SOTs, although, they often do not lead to the desired business performance (see dimension 1). Summarizing, networks and transdisciplinary collaboration are an important factor for effective technology transfer, especially in emerging knowledge areas (Borge & Bröring, 2020). In order to reach a sustainable transition it might be worth to consider SOTs as a kind of a ‘door opener’ to new networks to improve a company’s ambidextrous capabilities of balancing the exploitation and exploration of new knowledge, which is highly important in the context of sustainable innovations (Cillo et al., 2019). However, the role of networks has not been explicitly mentioned as criterion, when selecting a new technology. That might be explained by the particularly interdisciplinary character of SOTs (Borge & Bröring, 2020), which are often systemic (Bröring et al., 2020) and require collaboration with other actors in the value chain.

For dimension (4) *institutional and regulatory frames*, it should be highlighted that, in contrast to previous literature (e.g. Jain et al., 2003), we derived two distinct clusters, one for *industry supporting conditions* and one for the *compliance with political and legal frameworks.* The first includes criteria, which are frequently mentioned in literature in the context of SOTs, also in terms of drivers for the emergence of SOTs (Horbach et al., 2012). The latter refers to criteria particularly suited for industry (e.g., statement 50, *the presence of industry standards for the application of the new technology*), which has also been described in the context of political and legal frameworks, but not as extensive. Also, as our results show, these criteria might have to be considered separately based upon the perspective of industry stakeholders.

Next, we will discuss our results with a focus on the different stakeholders along the value chain. A possible explanation why the agricultural and feedstock industry evaluates *compliance with political and legal frameworks* as highly relevant is that especially the agricultural industry as the raw material provider is traditionally faced by many political restrictions. The highly rated relevance of firm-specific competencies corresponds to literature from the strategic management view (e.g., resource-based view, dynamic capability or absorptive capacity) (Dangelico et al., 2017; Del Río González, 2005). However, our results show that there are differences between actors along the value chain. The agricultural and feedstock industry is a bottleneck for a sustainability transition as they deliver the bio-based material, which was also specifically mentioned as a selection criterion in our study (cf. statement 10, *the availability of bio-based resources).* Thus, in order to facilitate the market implementation of SOTs the agricultural and feedstock industry needs special support to compensate missing competencies at the beginning of the value chain. On the other hand, this might be challenging, since the agricultural and feedstock industry perceives *networks and open innovation* as least relevant. This might imply that they still rather rely on internal resources and capabilities.

Within the (bio)-chemical industry, the *technical feasibility* has a high and, among the participating companies, coherent priority. Here, for instance, *the securing of an equivalent quality as a conventional alternative* (14) is perceived as highly relevant. This criterion is across all stakeholders perceived as highly relevant. This might be an indicator for a general challenge that industry throughout the value chain has to deal with in the context of sustainability transition, as society is not ready to change its behavior or consumption habits. Additionally, for the (bio)-chemical industry *the availability of bio-based resources* (10) is highly relevant when selecting emerging SOTs. Companies often strive for eco-efficiency, seeking to reduce the environmental harm caused by industrial activity while increasing productivity, which is not sufficient to achieve a sustainability transition (Hellström, 2007; Szekely & Strebel, 2013). This argument can be supported by statement 26, *the possibility to increase efficiency within existing processes and infrastructure*, which was rated as rather highly relevant by all stakeholder groups except from the (bio)-chemical industry. This might show that the (bio)-chemical industry is already striving for more systemic changes associated with an emerging SOT. Furthermore, it is worth mentioning that we observed a higher willingness among (bio)-chemical companies to participate in our study than among the agricultural and feedstock, and consumer industry. This could be also a sign for the (bio)-chemical industry's interest in the perceptions of other stakeholders along the value chain and the awareness that there is a need for systemic SOTs (Rigall & Wolters, 2019).

Within the consumer industries, the *ease and controllability of technology integration* is perceived as a particularly relevant cluster. That could imply that they are still less willing to change existing systems, i.e., existing value chains and infrastructures. That might also be explained by their traditionally low R&D efforts. Accordingly, there is still potential for, on the one hand, more intense collaboration between actors along the value chain to circumvent the challenges for companies with respect to changing infrastructures and value chains and, on the other hand, public education to also prepare the society for systemic changes, which might lead to deviating consumer experiences when striving for sustainability transition. Although the cluster *industry supporting conditions* has been averagely rated by the consumer industry as least relevant among the four stakeholder groups, statement 50 (*the presence of industry standards for the application of the new technology*) is more relevant for the consumer than for the (bio)-chemical or agricultural and feedstock industry. This, again, might go along with the consumer industries' demand for the technology's *ease and controllability of technology integration*. Another proof for this argument is the high rating of *the compatibility of the new technology with existing manufacturing processes of the customer* (37) falling within the cluster *economic viability.* Further, *the possibility to develop new market potentials* (20) and *the technology's potential to cause a systemic change of value chains beyond the company's boundaries* (54) are less relevant for the consumer industry than for the agricultural, feedstock and (bio)-chemical industries. Criterion 54 may relate to the anticipation of a SOT's potential to become a dominant design referring to its standard setting potential (Berg et al., 2019). Interestingly, this criterion was one of the least coherently rated criteria among all stakeholder groups.

The perception of consultancy and industry networks is not shown in Figure 3.5. However, Table 3.4 shows that interestingly, the cluster *industry supporting conditions* is perceived as more relevant for consultancy and industry networks than for the actual manufacturing companies, i.e., industries. Also, *access to networks and open innovation* are perceived as more relevant by consultancy and networks, which was expected as they represent the networks themselves. It might show that they have a wider perspective and are more able to look beyond technological and industry domains while recognizing the potential emerging SOTs might involve in terms of new networks and collaborations.

Finally, we will discuss our results with a focus on the selection criteria's relevancy for SOTs resulting from incremental or radical innovations, as it should be mentioned that technology selection is per se different if selecting technologies resulting from incremental or radical innovations. The differences especially occur due to the different innovation processes, companies' development objectives and varying time horizons when innovating. Thus, small and medium-sized enterprises (SME) may rather focus on the short term, while larger companies are rather long-term oriented when implementing sustainable ideas. Accordingly, sustainable innovations within SMEs are more of an incremental nature, whereas larger companies tend to implement radical innovations (Bos-Brouwers, 2010). Furthermore, projects for radical product innovations are managed less flexibly than projects for incremental innovations. Managing radical projects with more structure and less flexibility may be a means of mitigating the increased level of risk. Ideas for radical development projects most often come from formally planned activities, while ideas for incremental development projects most often come from informal practices (Holahan, Sullivan, & Markham, 2014). For radical innovations, rather qualitative criteria, such as company's visions and goals or portfolio fit are applicable within the evaluation process. In contrast, to evaluate incremental innovations quantitative decision criteria including financial measurements such as net present value or rate of return are applicable, as it is easier to obtain references to similar technologies or products (Montgomery, 2017).

Accordingly, appropriate criteria to evaluate radical innovations are allocated to the cluster *value of sustainability.* More precisely, the criteria *the increasing importance of sustainability rankings for companies* (5) or *the increasing importance of "sustainability" for groups of investors, which possibly facilitates capital procurement (e.g., Environment, Social, Governance (ESG) criteria)* (7) seem most appropriate to evaluate radical innovation. However, the criteria *the possibility to get a certification for the sustainability of the technology* (25) and *the confirmation of sustainability for example via a LCA* (42) are more challenging to apply for radical innovations, as a relevant anchor point, i.e., a similar technology, might be missing. Most criteria within the cluster *external communication and customer orientation, future* *competitiveness, corporate entrepreneurship* and *access to networks and open innovation* might be relevant for radical innovations.

In contrast, most criteria referring to *economic viability* and *technical feasibility* are easier to apply on incremental SOTs (Montgomery, 2017). Most criteria in our study sorted to the cluster *presence of needed capabilities* are probably more relevant for radical innovations. However, *that own employees are able to understand and evaluate the technology* (47) could be more applicable for incremental innovations, as radical innovations require major shifts in assets including human resources (Montgomery, 2017). The *institutional and regulatory frames* including *industry supporting conditions* and *compliance with political and legal frameworks* are relevant for incremental and radical innovations alike. However, in the context of more radical innovations political frameworks might be less stable. This makes it difficult to apply the criterion of *the planning reliability for the future existence of political framework conditions* (16) for radical innovations. In general, regulatory and policy issues are particularly important for SOTs, whether they are of an incremental or radical nature, because the market can be very regulation-driven (Horbach et al., 2012). All in all, all criteria derived in our study might be important for both types of innovations. However, some are more relevant for SOTs resulting from incremental and others more relevant for those resulting from radical innovations.

3.6 Conclusion

Sustainability transitions from a fossil-based towards a bio-based economy go along with systemic changes. Accordingly, the involvement of different stakeholders in technology evaluation and selection during transition processes seems pivotal. The literature on technology selection is quite fragmented. Our research presents a first study including a composition of criteria relevant for selecting and evaluating technologies, especially SOTs, from distinct business perspectives accumulating to a value chain spanning perspective. We incorporated four different stakeholder groups along different value chains of the bio-based economy, i.e., (1) agricultural and feedstock, (2) (bio)-chemical, (3) consumer industries and (4) consultancies and networks. To answer RQ1 (“What are the criteria for selecting a sustainability-oriented technology from a value chain spanning perspective in the case of the bio-based economy?”), we derive 59 selection criteria for SOTs being sorted into 11 clusters. These clusters are summarized into four dimensions. Accordingly, the implementation of SOTs involves (1) market environment and viability, (2) corporate strategy and technology integration, (3) capabilities and knowledge exchange and (4) institutional and regulatory frames.

3.6.1 Theoretical implication

This mixed-method research study contributes, first, to knowledge on sustainability transitions along value chains combining insight from transition theory and characteristics of SOTs resulting from systemic innovations. Next to providing an overview of 59 selection criteria for SOTs, we extend existing literature by two new groups of such technology selection criteria, namely the *value of sustainability* referring e.g., to *the increasing importance of sustainability for groups of investors, which possibly facilitates capital procurement (e.g., ESG criteria)*, and *networks and open innovation* referring e.g., to *the potential to access new networks or connect with start-ups* associated with the emerging SOT.

Second, by taking a value chain spanning perspective, we are able to answer RQ2 ("How do the perceptions of relevancy of these criteria differ between stakeholders along value chains of the bio-based economy?") and contribute to the understanding of coherence vs. non-coherence in technology evaluation across different value chain actors. Our data reveals that in terms of *external communication and customer orientation* as well as *future competitiveness* (market dimension) all stakeholders agree that these criteria are highly relevant. Sustainability transitions are long-term and multi-dimensional transformation processes (Markard et al., 2012), which are accompanied by incremental and radical technological innovations (Bröring et al., 2020; Szekely & Strebel, 2013). However, we show that companies (or even industries) throughout the value chain rate short-term oriented criteria sorted for instance among *technical feasibility* and *ease and controllability of technology integration* as comparatively high. *The access to networks and open innovation* could be for instance matched with the long-term goals to be pursued in sustainability transition. However, here we showed that these criteria have been rated as comparatively low, especially by the agricultural and feedstock and consumer industries. Hence, for transition theory, that means actors along the value chain reveal varying readiness for long-term changes being necessary for sustainability transitions. However, according to transition theory, besides technological innovations leading to changes on the micro level, changes of the socio-technical regime (incl. e.g., industry, science and markets) as well as the overarching socio-technical landscape level need to interact to ultimately cause a transition (Vandermeulen et al., 2012).

3.6.2 Practical implications

From a practical point of view, the different criteria should gain specific attention within technology and value chain management. For example, as *external communication and customer orientation* are a highly relevant technology selection criteria for all stakeholders, the entire customer experience should be incorporated by, e.g., including the customer already when developing new SOTs to not overstrain the customer after commercialization. Depending on the corporate strategy, different criteria might be more relevant. For instance, companies with a short-term focus prefer incremental innovations over radical ones, as they are more predictable (Montgomery, 2017). Accordingly, criteria related to economic viability or technical feasibility are more relevant for this kind of companies.

Additionally, the participants in the group discussion identified a lack of expertise in the evaluation and implementation of an emerging SOT as one of the bottlenecks for the widespread adoption of SOTs. In addition to the highly perceived relevancy of internal competencies within the agricultural and feedstock industry, we can draw the proposition that it is difficult for the agricultural and feedstock industry to gain access to the required external expertise perhaps due to certain structural industry characteristics. Firms from these sectors are characterized by low R&D intensity, difficulties in accessing funding, SMEs and a conservative attitude towards new technologies and diversifying business models (Calleja et al., 2004; Del Río González, 2005). The first step in overcoming these barriers is for SOT developers to recognize these distinctive industry characteristics and work on solutions that address multiple bottlenecks at once, preferably in a co-creative manner with the implementing firm to enable a co-development and therewith the alignment of potential interfaces. It has been shown that the involvement of the implementing firm in the innovation process leads to an increase in problem ownership of the sustainability impact and acceptance of the technology, than if it had been developed in isolation (Lang et al., 2012). Industry initiatives are aware of the industry-specific challenges and support firms through activities such as networking, scouting and consulting in the evaluation and selection of the most promising SOT for their purpose and support the bio-based economy to establish itself as a competitive economic paradigm.

Besides active engagement in open innovation approaches with innovating firms and participation in industry networks, the implementing firm should enable organizational structures that allow cross-functional and cross-organizational collaboration to increase absorptive capacity and bridge internal knowledge gaps, thus building the necessary assessment and implementation capacity for SOTs (Messeni Petruzzelli et al., 2011). Firms can begin to leverage existing relationships and integrate the knowledge available in the value chain into their management practices and decision-making processes. Also, in times of industry 4.0, in order to achieve and align requirements throughout the value chain and product life cycles, digital technologies can contribute to more sustainable solutions (Rusch, Schöggl, & Baumgartner, 2021). Accordingly, AI can be used to collect and generate data for an LCA that has been also mentioned as a selection criterion. To track and foster the usage of waste- and side-streams of production processes and value chains, several start-ups are already using theses digital technologies (see e.g., Ellen MacArthur Foundation, 2022). Firms are also encouraged not to evaluate SOTs for their seamless substitution potential, as they are unlikely to be able to compete with the existing technology base used in the firm. Instead of considering the sustainability aspect of a technology as an additional attribute in their evaluation, managers should develop strategies to capitalize on this sustainability aspect. The increased importance investors attach to sustainability rankings will ensure long-term profitability and competitive advantage by pursuing a holistic sustainability strategy that puts SOTs at the center of their activities. In order not to miss the technological opportunities offered by SOTs in favor of considering conventional selection criteria, firms should shift the relative importance attached to selection criteria from conventional ones to those that take sustainability benefits into account.

Additionally, the results of our study visualized by different maps can be used as a guidance for targeted action planning and the evaluation of research projects to assess their future financial supportability. For instance, as an extension of the actual GCM process as described in this paper after having finalized the list of 59 selection criteria, we used the selection criteria derived in our study within a workshop with researchers in the domain of biotechnology, chemistry and plant breeding in order to evaluate a specific SOT in the context of a research project on plant protection. In the workshop the participants were asked to consider the list of criteria and should decide how their technology performs in each criterion. Insights during the workshop showed that it is useful to provide researchers stemming from the biotechnology or chemical field, thus often not possessing sufficient technology management skills, a framework of technology selection criteria from business perspective to foster technology transfer from lab scale to commercial applications.

3.6.3 Policy implications

Political strategies such as the European Green Deal or the United Nations' Sustainable Development Goals (SDGs) also support the emergence of sustainability-oriented technologies from a regulatory-push perspective (Arash et al., 2020; Horbach, 2008). This institutional debate reflects the socio-technical landscape level from the multi-level perspective on transitions. It puts pressure on the existing socio-technical regime and at the same time triggers the emergence of niche technological innovations, which are referred to in our paper as SOTs (Geels & Schot, 2007). This was the starting point of our paper while seeking to explore how SOTs are selected by different regime actors, such as business stakeholders, to give recommendations for targeted support initiatives on socio-technical landscape level to facilitate the technology transfer in the context of sustainability transitions.

As policy implications, our participants emphasized that regulatory certainty and planning security regarding the economic viability of the technology, independent of subsidies and, in the event of changing regulations, the threat of sanctions, are important aspects to be considered regarding the regulatory framework of a SOT. Due to the positive social and environmental impacts of SOTs, policymakers have an interest in their broad market implementation and therefore adopt laws and regulations that promote their broad transfer and diffusion. However, regulations only reflect the current knowledge base about the sustainability impacts of SOTs and need to be adjusted if unexpected implications and emerging social injustices arise from the implementation of certain solutions that were once promoted by regulation. If existing regulations need to be amended, this should be done in a predictable and credible manner and if new regulations are adopted, they should be evidence-based and provide an appropriate transition period (Mickwitz, Hyvättinen, & Kivimaa, 2008). The economic viability of a technology investment should therefore, if at all, only initially depend on subsidies and go along with a realistic planning horizon to enable amortization of R&D costs, so as not to be vulnerable to changing regulations.

3.6.4 Limitation and future research

Reflecting on the practical applicability of the selection criteria derived in our study within companies, we admit that not all criteria might be directly applicable to the evaluation of an emerging SOT. However, the criteria show which dimensions lie behind the evaluation process of companies when deciding or choosing a new SOT. For example, statement 7 (*the increasing importance of "sustainability" for groups of investors, which possibly facilitates capital procurement (e.g., ESG criteria)*) belonging to the *value of sustainability* has not been described in literature in the context of technology evaluation so far. A reason for this might be that the criterion is rather a driver for implementing a SOT but not a specific selection criterion. Nevertheless, it was mentioned by the stakeholders in our study and shows that it plays a role while evaluating SOTs and thus needs to be considered by stakeholder groups. Although, we already applied these criteria within a workshop with researchers on a SOT in the context of plant protection, future research needs to validate our criteria with different SOTs and different industry stakeholders.

We did not focus on a very specific industry, but rather on the wider industry context of the bio-based economy covering various industries, such as the agricultural or chemical industry. Thus, we assume that the evaluation criteria derived in our study are applicable in various manufacturing industries. However, it should be mentioned that there are various ways to achieve greater environmental sustainability, such as the transition towards a bio-based economy or the concept of circular economy (Di Maria, Marchi, & Galeazzo, 2022). The clusters derived in this study are generalizable and might be applicable in various transition processes where actors face similar problems such as (missing) compatibility with existing technological regimes which only gradually change). However, we have to consider that the evaluation of technologies and the weighting of the individual criteria might be different depending on the technological field (Zemlickienė & Turskis, 2020). Accordingly, although we did not specifically exclude other contexts such as the circular economy, results, hence selection criteria for SOTs, might slightly differ. Within the circular economy the major focus is not on the substitution of fossil raw material by bio-based alternatives, but rather on eco-efficiency and the use of recycled fossil resources (D'Amato & Korhonen, 2021).

Although theoretically and practicably justified, the number of 11 experts contributing to the group discussion and the number of 40 and 49 experts participating in the sorting and rating process impede a wide generalizability of our results. Also, in the online discussion, we were only able to include one company from the consumer industry. We consider this as a limitation of our study. In the second part, in the rating process, 8 stakeholders from the consumer industry participated. We admit, that the results are hardly representative for the entire consumer industry. Nevertheless, they provide first insight into the differences between stakeholder types. In comparison to bigger surveys potentially allowing the inclusion of a more representative sample, the benefit of GCM is to obtain more in-depth insight into the stakeholders' perceptions. Our aim is not to provide an all-encompassing list of technology selection criteria that companies can ultimately use. But rather to reveal that there are different stakeholder perspectives including different priorities, which need to be considered when evaluating and selecting SOTs.

Further, this study does not incorporate country specific differences. On the one hand, we included participants stemming from Germany or Switzerland. On the other hand, many of the companies for which the participants are working can be classified as large multi-national corporations. However, as we know the individual background of the participants, we can claim that they rather identify themselves as European and hence reflect the perception of a European company and thus the European market. This is for instance particularly relevant for selection criteria referring to the compliance with political and legal frameworks, which are certainly different across the world. Accordingly, the applicability of our results is limited to the European market.

Our data represents the personal perception of the participants, which has been used to reflect the respective industry perspective. That is a reasonable approach in GCM studies, however, it has to be remarked that within bigger companies, perceptions on company level between employees might differ. In order to overcome the limitations of our results, future research could include more than one participant from each company and take the average over all participating employees. We have mapped a value chain spanning perspective on the evaluation of SOTs to do justice to their systemic character. However, future research might dive deeper into our results and derive a differentiation of criteria being more relevant for the selection of autonomous SOTs or more relevant for systemic SOTs. The same applies for the differentiation between the evaluation of SOTs resulting either from incremental or radical innovations, where the relevancy of individual selection criteria might differ. There might be a gap between what stakeholders are claiming as relevant selection criteria and how they evaluate SOTs in reality. In order to circumvent the limitation of GCM studies, experiments such as discrete choice experiments (Wensing, Caputo, Carraresi, & Bröring, 2020) or case studies might be conducted (Lee & Kim, 2011; Stalmokaitė, Larsson Segerlind, & Yliskylä-Peuralahti, 2022). Also, larger surveys could validate the constructs we created and elaborate on indicators measuring the technology selection criteria.

4 Assessing emerging technologies from an ecosystem perspective

Chapter 4 answers the following research question:

RQ 4: How do companies position themselves to achieve bargaining (market) power and a competitive advantage in an emerging digital business ecosystem?

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This chapter is based on the following publication:

Block, C., Bohnsack, R., Rennings, M, & Bröring, S. Control point dynamics in emerging digital business ecosystems: The case of digital agriculture**.** *(to be resubmitted)*

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4.1 Introduction

Traditionally, many industries were focused on value creation and value capture by producing and selling physical products (e.g., car industry, mobile phone industry or agricultural industry) organized in a traditional linear value chain. Competitive advantages and an industry's bargaining position vis-a-vis its group of suppliers and buyers as well as threats by substitutes or new entrants could be evaluated given this defined industry structure (Porter, 1980) or a certain value chain position (Peppard & Rylander, 2006). Nowadays, a company's performance and value creation increasingly rely on actors outside the traditional value chain, which is moving towards business ecosystems (Iansiti & Levien, 2004). Especially with the emergence of digital technologies, linear value chains are replaced by value networks and digital ecosystems, consequently, industry boundaries are blurring and market entry for technology companies or start-ups into traditionally product-centric machinery industries is facilitated. Thus, the traditional value creation logic no longer holds and a new bargaining situation emerges, where, besides competition, cooperation and value co-creation plays a much more relevant role than in the physical world (Dattée, Alexy, & Autio, 2018). In such digital business ecosystems, products are generally based on a layered modular architecture allowing the extension of physical products with digital capabilities. This architecture bridges hierarchically arranged components of physical products with modules of digital functionality configured into layers (Hylving & Schultze, 2020). Lower layers (i.e., physical products or networks) provide and enable functionalities to higher layers facing the user (i.e., digital services or content) (Bohnsack, Kurtz, & Hanelt, 2021; Yoo, Henfridsson, & Lyytinen, 2010). Assuming that all layers (potentially occupied by different players across industries) are necessary to deliver an overall value proposition (VP) to the customer and given the speed and dynamics of digital technologies (Bharadwaj, El Sawy, Pavlou, & Venkatraman, 2013), securing long-term competitive advantages requires breaking traditional industry structures and moving towards business ecosystems that allow for jointly generating an ecosystem value proposition (EVP) (Hanelt, Bohnsack, Marz, & Antunes Marante, 2020; Jacobides, Cennamo, & Gawer, 2018; Talmar, Walrave, Podoynitsyna, Holmström, & Romme, 2020). We understand digital business ecosystems as digitally enabled value networks, where value is created in interdependent relationships (Pagani, 2013; Peppard & Rylander, 2006) and captured by participant's relative bargaining power (Brandenburger & Stuart, 1996).

In traditional linear value chains, single companies, being vertically integrated along the value chain, are usually covering all core value creation activities and hence control of value capture (Pagani, 2013) – this logic does not hold for value networks such a digital business ecosystems. By contrast, digital business ecosystems require companies to give up their control of the mechanisms behind value creation and capture (Dattée et al., 2018). This holds especially true for complex VP where a single firm typically does not possess all resources to generate and commercialize them (Appleyard & Chesbrough, 2017). For example, in the car industry digital technologies have led to the emergence of the connected car ecosystem. It is not the car manufacturers anymore, who have the entire control over the car as a VP. While adding to the physical product layer (i.e., car), other actors, such as Apple, Google or Rovio Entertainment, provide additional digital services and content to the user and, thus, contribute to value creation as well as value capture (Bohnsack et al., 2021). Thus, value creation for the customer and ultimately value capture is distributed over different actors and layers within the digital business ecosystem.

To address this issue of distributed control especially in digital business ecosystems and the mitigation of risks from openness, scholars introduced the concept of control points (Rukanova, Reuver, Henningsson, Nikayin, & Tan, 2020), which can be used while constructing new viable business models (Eaton, Elaluf-Calderwood, & Sorensen, 2010; Trossen, 2005). Extant theory such as industrial organization (IO) theory or the resource-based theory (RBT) are useful to analyze how firms gain a competitive advantage through being e.g., able to erect entry barriers for competitors (Porter, 1980) or if firms possess valuable, rare, inimitable and non-substitutable resources to create a sustained competitive advantage (Barney, 1991; Wernerfelt, 1984). However, they have been criticized as being too static (Ambrosini & Bowman, 2009), focusing on value capture in the form of monopoly rents (Pitelēs & Penrose, 2002) or being too focused on resources owned and controlled within company boundaries (Amit & Zott, 2001; Dyer & Singh, 1998). Accordingly, these theories do not capture the possibilities arising in the digital world and its emerging digital business models (Morgan, Feller, & Finnegan, 2013), as digital business ecosystems seek cooperation and contribution from multiple actors.

This paper introduces the concept of control points inspired by IO theory and the RBT in the context of strategic management. The concept of control points allows for a cross-industry and much more dynamic evaluation of bargaining power of individual actors within a digital business ecosystem. Bargaining power is the power to capture value from the common EVP. It depends on whether an actor possesses certain control points (Gambardella & Panico, 2014). It is increasingly important how companies are able to control interfaces (and an increasing number thereof) between companies or entire sectors as well as different layers within the layered modular architecture (Bohnsack et al., 2021; Staudenmayer, Tripsas, & Tucci, 2005).

This is particularly important in the increasingly entangled ecosystem of the digital world, as profits and competitive advantages within a digital business ecosystem are dynamic throughout the digital business ecosystem and accumulate at control points (Pagani, 2013). That means, actors who hold these positions have great control of how the digital business ecosystem works and how benefits are redistributed. According to Pagani's (2013) definition, control points are the positions of greatest value and/or control of participants within a given value network (e.g., digital business ecosystem). Accordingly, a control point allows for superior profits. For instance, for companies striving to move from a linear towards a platform-based business model, the occupation of strategic or technical control points, such as brand or infrastructure, might enable value capture and reduces risks resulting from openness (Van Dyck et al., 2021). In this regard, Pagani (2013) reveals that in a multisided platform business model such as eBay, where a platform owner / aggregator brings together different groups, e.g., buyers and sellers have the greatest control on value creation and value capture in the entire ecosystem. In other multisided platforms such as Apple, the platform owner has the greatest control on value creation and value capture. With an increasing number of participants and interactions the focal actor in a digital business ecosystem increases its bargaining power (Brandenburger & Nalebuff, 2011; Jacobides, Knudsen, & Augier, 2006).

Despite a growing literature on digital (business) ecosystems (Gawer, 2021; Hanelt et al., 2020; Jacobides, 2022) and a blurring of conventional industrial logics (Sick & Bröring, 2022), there is still limited understanding of how incumbents and new emerging actors can establish a new or adapted bargaining position enabling a superior value capture mechanism. There is a lack of conceptualization of the integration of both concepts: the layered modular architecture (Bohnsack et al., 2021; Yoo et al., 2010) and control points (Dattée et al., 2018; Pagani, 2013). For companies to derive strategies, it is important to understand which layer(s) and, with this, which actor(s) have greater bargaining power within the digital business ecosystem. In addition, it remains unclear which control point constellation within the digital business ecosystem may lead to a superior position, hence a competitive advantage in a digital business ecosystem.

We address these research gaps by exploring how companies position themselves to achieve bargaining (market) power and a competitive advantage in an emerging digital business ecosystem. To this end, we conduct a multiple-case study in the agricultural sector. We use the agricultural sector as a case example as this is a sector where digital technologies - driven by an increasing world population and the need for a more precise and sustainable farming system - is expected to evoke tremendous changes of incumbents' business models in the future (Dörr

& Nachtmann, 2022). Furthermore, the digital agricultural ecosystem is currently gaining considerable interest from global technology companies and an increasing number of AgTech start-ups. In contrast to other industries, such as the information and communication technology (ICT) industry, which is a prime example for the layered modular architecture (e.g., Dattée et al., 2018; Yoo et al., 2010), case studies on the influence of digital technologies on other ecosystems, such as on ecosystems in the agricultural industry, and their underlying business models is rarely explored in management. In line with Pagani's (2013) and Dattée et al.'s (2018) suggestions, control points are analyzed in this paper in terms of how and how much value they create and capture to operationalize different bargaining positions.

Eventually, this paper contributes to the operationalization and understanding of the emergence and occupation of different sets of control points in emerging digital business ecosystems. Our findings reveal that missing standards and interoperability are addressed by traditional machinery producers and technology providers alike by occupying control points at interfaces between various actors in the digital business ecosystem. Accordingly, by owning a specific set of control points that enables to control access to the ecosystem or gaining deeper inside into the user through data generation, actors seek to further leverage their bargaining power. We derive three generic strategies based upon different going-in positions how actors in emerging digital business ecosystems occupy control points.

4.2 Theoretical background

4.2.1 Digital business ecosystems

Digital business ecosystem is an extension of the business ecosystem concept defined by Moore (1993). A business ecosystem is an economic community of interacting, loosely coupled companies that produce valuable goods and services while operating outside traditional industry boundaries (Moore, 1993). There is a plethora of studies adopting an ecosystem approach (see Aarikka-Stenroos & Ritala, 2017) focusing on concepts such as innovation ecosystems (Dattée et al., 2018), digital ecosystems (Pagani, 2013) or platform ecosystems (Gawer & Cusumano, 2014; Van Dyck et al., 2021). In this paper, we refer to the concept of digital business ecosystems encompassing or at least overlapping with the various aforementioned ecosystem concepts (Hanelt et al., 2020).

A digital business ecosystem puts digital technology into the center and relies on digital technology infrastructure and the network of various entities (e.g., software applications or digital service) and actors contributing to the overall value creation (Senyo, Liu, & Effah, 2019). Digital business ecosystems are characterized by interacting organizations being digitally connected and enabled by modularity. Within digital business ecosystems, an organization finds complementors for complementary goods and services, when the organization is not able to deliver these add-ons on its own (Jacobides, Sundararajan, & Van Alstyne, 2019).

Especially in fields with rapid technological progress, complex networks of various members are important (Powell & Grodal, 2005). This largely applies for digital business ecosystems, which gain relevance for actors across different industry sectors apart from IT and software industry (Hanelt et al., 2020). In contrast to Adner's (2017) definition of ecosystems characterized by “defined positions and activity flows among them“ (p. 42) to achieve a collective VP, participants and their positions in digital business ecosystems are much more dynamic and their VP might change quickly (Hanelt et al., 2020; Yoo et al., 2012). Platform ecosystems are an example of a digital business ecosystem. In platform ecosystems, a platform leader or hub actor usually owns and governs the ecosystem while connecting various sides of the market (Gawer & Cusumano, 2014), such as eBay or Facebook. However, on the one hand there could be even more than one platform in a digital business ecosystem and on the other hand not every digital business ecosystem uses a platform as a central hub (Aarikka-Stenroos & Ritala, 2017; Senyo et al., 2019). Hence, in the digital business ecosystem of connected cars, upstream component offers (e.g., sensors or connectivity provision) need to be integrated with the focal offer itself, i.e., the connected car that interacts with downstream complement offers (e.g. other physical products such as cars, laptops, smartphones, advanced navigation systems, or entertainment services) (Bohnsack et al., 2021; Kapoor, 2018).

The example shows that digital business ecosystems also lead to new interdependencies between business models being designed around a certain VP, the value network and the revenue-cost model (Bohnsack et al., 2014). Digital services (e.g., dedicated navigation systems) alone will not generate any value if not appropriately connected with other business models on other layers (e.g., selling or leasing cars). Likewise, the distribution of value capture within the digital business ecosystem gathered around a focal offer, up- and downstream complements needs to be negotiated (Kapoor, 2018). Eventually, a company’s decision to participate in a digital business ecosystem and thus leave their traditional environment (i.e., the linear value chain and industry boundaries), where the bargaining situation in the buyer - supplier relationship is usually known, goes along with the gradual digital transformation of the firm and a step into an area of ambiguity, where the new distribution of control requires definition (Kapoor, 2018; Rukanova et al., 2020). Hence, the next section will explore the interplay of value creation and value capture on control points particularly evident within digital business ecosystems and their underlying digital business models.

4.2.2 Control points

Control points are located at the interfaces between two or more actors where value creation takes place and where value capture is negotiable. The concept of control points was introduced by the Value Chain Dynamics Working Group at MIT in order to understand how commercial benefit could be gained from business models emerging in and around the telecommunications industry (Trossen, 2005).

According to Pagani's (2013) definition, control points are the positions of greatest value and/or control of participants within a given digital business ecosystem. For example, within the Apple App store digital business ecosystem, Apple holds the control point “App Store” aggregating various applications, whereas the developers hold the control point over applications and the mobile operator owns control points referring to network connectivity (Eaton et al., 2010). For companies facing the shift from linear value creation to value networks, i.e., joint value creation, the occupation of control points might enable value capture and reduces risks resulting from openness (Van Dyck et al., 2021). Dattée et al. (2018) understand control points within an emerging digital business ecosystem as an envisioning of the right partner selection or the identification and occupation of strategic bottlenecks to gain control of the ecosystem and its overall VP with the goal to capture value in the future. Moreover, their study rooted in the IT and telecommunication industries reveals that firms can pursue different ecosystem strategies, i.e., choose between configurations of interdependencies with component suppliers and complementors, and control points based on strong intellectual property (IP) or unique customer access depending on corporate strategy. Hence, overall the concept of control points is directly linked to the idea of business models describing how an organization creates, delivers and captures value (Osterwalder & Pigneur, 2010; Teece, 2010).

However, emerging digital business ecosystems go along with the complexity of the question what a defendable type of control point is (Dattée et al., 2018). In the emerging phase of the ecosystem, control may be dispersed among multiple actors in the ecosystem. The actual commercialization of a collective digital innovation might still be performed by an individual actor (Rukanova et al., 2020). Accordingly, firms need to establish dynamic control over the creation process, if they want to win the ecosystem game, i.e., gain a competitive position (Dattée et al., 2018). That means, a better understanding of different types of control points helps to explain how actors can gain a sustained competitive position in a dynamic setting such as digital business ecosystems - and design their business models accordingly. Dattée et al. (2018) argue that companies need to anticipate the future when setting control points, since control points can only help with value capture (if value has been created at all). For example, companies, such as Apple could control the architectural definition or vetting rights to allow membership in the ecosystem (Dattée et al., 2018), and thus protecting value capture in the future. In an ecosystem, IP of the developer of a technology can also be seen as a control point, as selling IP to other ecosystem participants might lead to IP revenues (value capture) in the future. Once companies have defined such control points for value capture, an internal business case for resource investments and appropriate tactics can be built (Dattée et al., 2018). Dattée et al. (2018) conclude that the identification of control points is an iterative and dynamic process accompanied by high uncertainty. In this regard, appropriate control points might help to pursue specific ecosystem strategies leading to different bargaining positions.

While Rukanova et al. (2020) rather focuses on the role of control points in terms of fulfilling certain tasks within a digital innovation process and does not reflect on the actors' intension of value creation and value capture when setting control points, Pagani (2013) and Dattée et al. (2018) particularly emphasize the influence of value creation and capture when defining control points. In this sense, we understand control points as the tension between value creation and value capture in digital business ecosystems, as value creation occurs by means of cooperation and value capture is determined by a bargaining relationship (Bowman & Ambrosini, 2000; Hannah & Eisenhardt, 2018; Van Dyck et al., 2021). However, control points are also shaped by regulations determining the power of certain control points (Elaluf-Calderwood, Eaton, Herzhoff, & Sorensen, 2011). Accordingly, we define a control point as follows:

A control point is a firm-created position in a digital business ecosystem which determines the possibility to capture value (today and in the future); the constellation of a set of control points is influenced by the firm's strategic position in the multi-layered architecture, the technical resources, and the institutional context.

Figure 4.1 summarizes our understanding of control points within a digital business ecosystem, which is characterized by a common EVP (Talmar et al., 2020; Thomas & Ritala, 2021). Such ecosystems can be found in e.g., telecommunication, autonomous driving, sustainable energy production or smart farming industry. For example, to be successful and competitive, Apple co-creates value with App developers, suppliers of additional components and other service providers to offer a EVP (Adner, 2012). To ensure that actors also capture the appropriate value from the joint value creation, the notion of control points comes into play that render a new lens to disentangle the interdependencies between joint value creation and value capture.

In digital business ecosystems, such as Apple, some actors, the orchestrator or platform owner, work as the direct interface to the customer and hence own the 'customer access' control point in the generic example shown in in Figure 4.1. If for example a new actor, a machine manufacturer or a digital service provider acts as the orchestrator, can vary between different digital business ecosystems. Still, all actors contributing to the EVP have individual connections to the end-customer reflected by the different arrows in the figure. A digital service provider can define APIs to ensure connectivity to the machine manufacturer (control point: 'modularity') and hence create value for the ecosystem. A machine manufacturer has for instance a remarkable image, thus the 'brand' can be seen as a control point, as it especially helps in keeping and increasing bargaining power and thus may lead to higher value capture for the actor holding this control point. A new actor holds a patent for a technology, which contributes to the overall EVP and for which it might capture value through licensing (control point: 'technical solution'). Thus, Figure 4.1 illustrates that various actors in a digital business ecosystem hold different control points leading to different degrees of bargaining power.

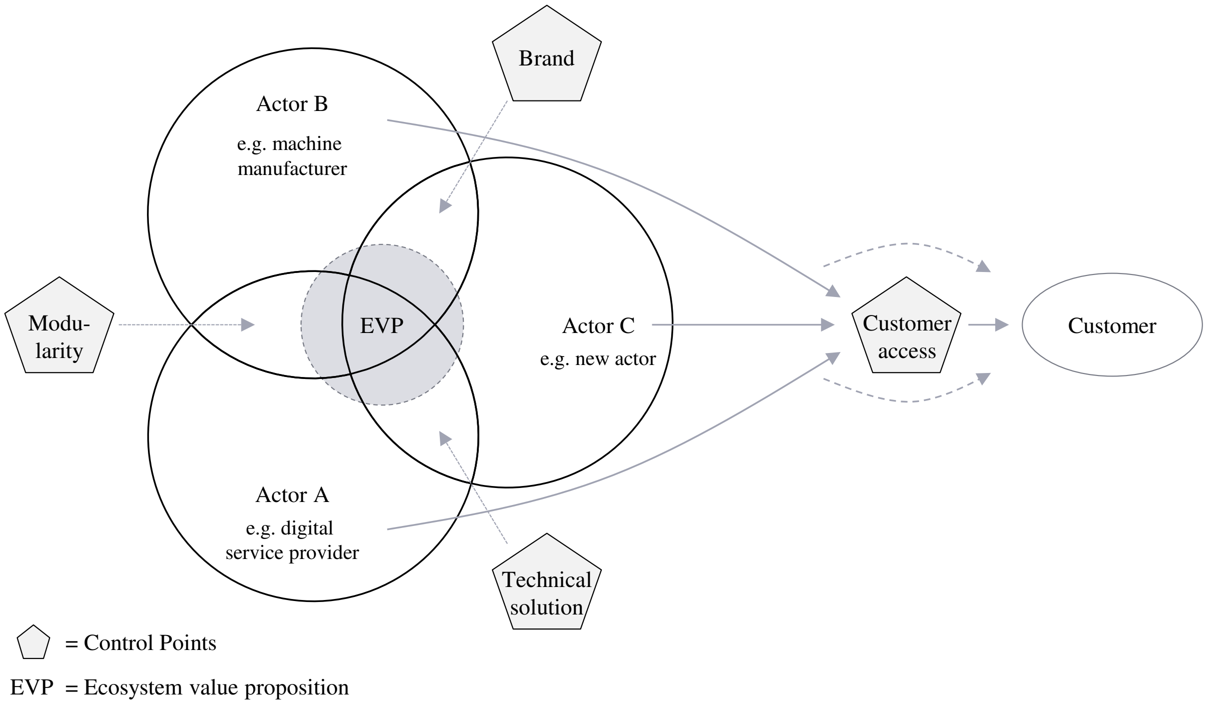

Figure 4.1: Conceptualization of control points and exemplifying control points in a digital business ecosystem.

Van Dyck et al. (2021) introduce two types of control points, namely intangible, strategic control points and formal, technical control points. Strategic control points include sociological and institutional control. Technical control points refer to technical solutions incl. property rights, which enable or restrict access to a firm's product(s) or ecosystem (Van Dyck et al., 2021). They also show that different control points need to be intelligently combined, to ensure that an actor captures value and reduces the risk of losing access. Accordingly, value might be created by the control point modularization, as opening leading to learning effects as well as an increase of data are leading to more innovation. To ensure continued access and value capture, companies may set a control point in managing the ecosystem's architecture by forming vertical integration across the value chain or horizontal alliances with direct competitors. However, so far it remains unclear which control point constellation of various actors within the digital business ecosystem may lead to a superior position, hence a competitive advantage in a digital business ecosystem. Moreover, it remains unexplored how control points are distributed across the layered modular architecture.

4.3 Methodology

In order to shed light on different actors' strategies within an emerging digital business ecosystem and various control point constellations, we applied an exploratory qualitative approach based on a multiple-case study design (Eisenhardt, 1989; Yin, 2016). This approach is suitable since control points is a new emerging phenomenon in (emerging) digital business ecosystems. It is still largely unexplored and only little empirical evidence exists. Thus, we aim to derive suggestions of how control points are set by firms and how they lead to a competitive positioning.

4.3.1 Empirical context

One sector where we can observe the phenomenon of emerging business ecosystems induced by digital technologies is the agricultural industry. It presents an appropriate case study to investigate our research gaps at hand, as it is an emerging digital business ecosystem characterized by joint value creation and the rise of novel EVPs on the one hand side. At the same time, it resembles a highly ambiguous setting where the race for market power between agricultural machinery producers, agricultural chemistry producers, IT companies and emerging AgTech start-ups is currently on and new business models are not well defined yet.

Figure 4.2 provides an overview of the evolution from physical products to a future autonomous digital ecosystem, where various systems (i.e., weather data, harvest, agricultural and machinery data systems) are integrated. The figure shows five different development stages originating from Porter and Heppelmann (2014). For our multiple-case study, we summarized these stages into three phases, namely phase 1 "past – before digitalization", phase 2 "current situation – emerging opportunities driven by digital technologies and phase 3 "future – creative destruction / increasing institutional changes". In the past, before the use of digital technologies the industry was characterized by the VP of selling physical products. Nowadays, precision agriculture technologies, predominantly using digital tools and information technologies to determine and manage variability in all aspects of agricultural production, play an essential role.

The aim is usually to realize higher economic returns by less input factors and with the positive side-effects of adding social and environmental value, e.g., by reducing the necessary amount of fertilizers, irrigation to mitigate draught and plant protection products (Pedersen & Lind, 2017; Pierce & Nowak, 1999). Thus, the VP is currently emerging towards an EVP consisting of a more holistic solution, which leads to challenges for incumbents positioning themselves in the emerging data-driven ecosystem eventually leading to the dissolution of standalone physical products such as agricultural machineries. In phase 3, i.e., in the future, with the increasing use of big data, machine learning and pattern recognition based on artificial intelligence (AI) -based cloud computing, agriculture could evolve into an autonomous data-driven digital ecosystem in which the machinery system (tractor) is less central and only one component of the overall system. Accordingly, on the higher-level digital technologies in the agricultural industry have impact on the evolution of the VP towards an EVP. At the same time, they have an influence on the product architecture itself.

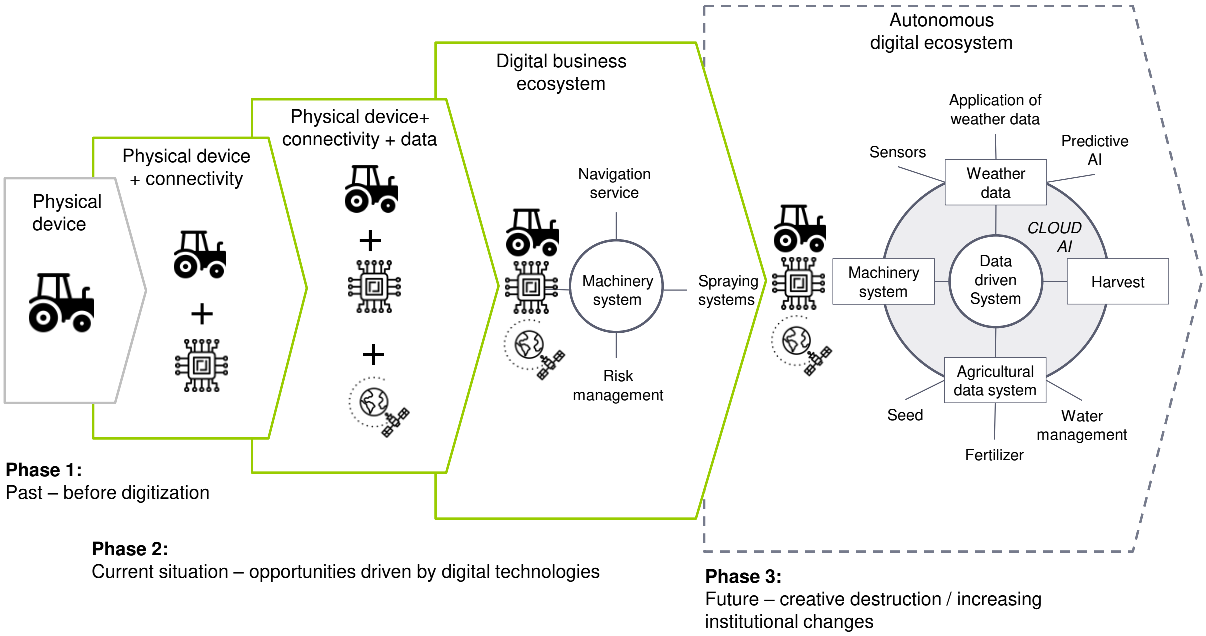

Figure 4.2: Evolution of the digital agricultural business ecosystem. Source: adapted from Porter and Heppelmann (2014).

The current market situation in the digital agricultural business ecosystem is best described by phase 2 or rather the transition from phase 2 to phase 3, which is the main focus of our multiple-case study. In phase 2, value still relies on selling physical products, but with the advent of digital technologies, value is increasingly created through data generation and its meaningful analysis. Figure 4.3 illustrates five layers of the emerging product architecture of the digital agricultural business ecosystem. The lowest layer shows physical devises / products in the form of tractors, equipment, or other physical inputs to the farmer. In this system, value is only created if data flow between different physical products and upper layers are enabled by certain standards or interfaces, thus connectivity is assured. The upper layers rely in the digital world. In the digital agricultural ecosystem analytics may include the use of AI and various data sources to predict the plant health on the field to provide decision support on the digital service layer in form of precise fertilizer or pesticide recommendation for the farmer. In addition, farm management information systems, which are often web-based software systems or apps that manage agricultural data and enable an easy handling of recording and documenting agricultural processes from soil cultivation to harvesting, are included in the digital service layer.[4]

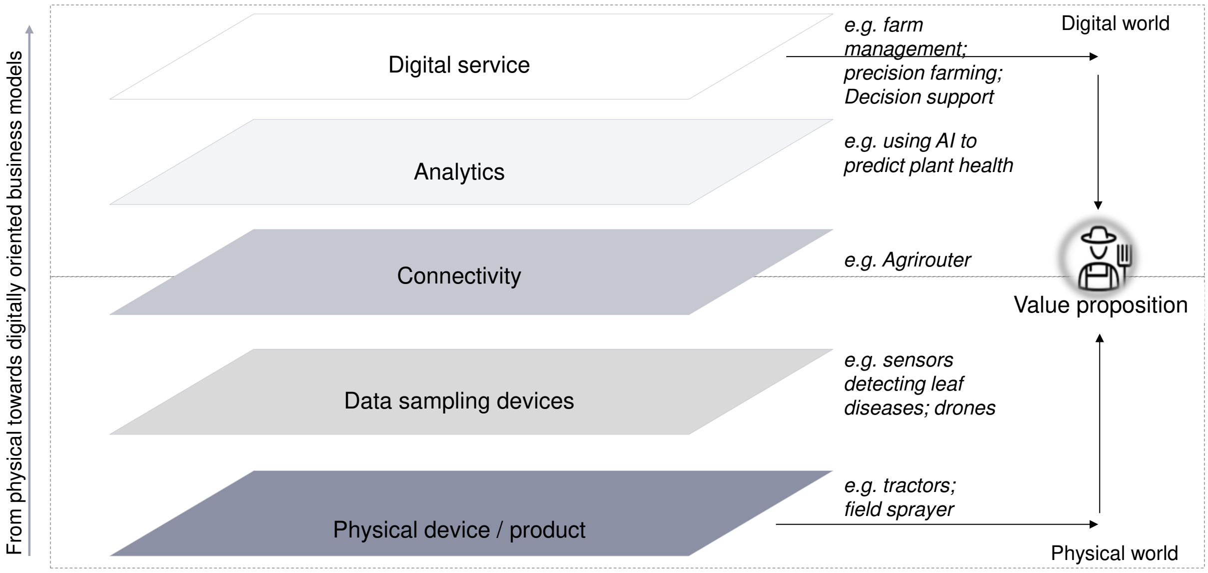

Figure 4.3: Product architecture within the digital agricultural ecosystem. Source: adapted from Fleisch, Weinberger, and Wortmann (2014) and Yoo et al. (2010).

4.3.2 Sample and data collection

To cover the digital business ecosystem of the agricultural industry, we sought to select experts from the most relevant sectors being engaged in the digitalization of the agricultural industry. Most interviewees were drawn from the pool of contacts which has been built up by the authors in the last few years being engaged in the field of digital agriculture and joining different innovation networks or industry associations. The companies were aggregated as strategic groups (Porter, 1980). Accordingly, we identified seven strategic groups (actor types), namely (1) large equipment manufacturers, (2) chemical (plant protection or fertilizer) manufacturers, (3)

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[4] It should be noted that depending on the literature and the perspective, there might be more or slightly different layers to add, such as the end-user layer in Kamilaris, Gao, Prenafeta-Boldu, and Ali (2016) or the session layer in Köksal and Tekinerdogan (2019). However, for the purpose of this study we refer to these five basic layers.

dealers, (4) software providers, (5) technology providers, (6) specialists / AgTech start-ups[5] and (7) the user group of farmers. We included the farmer in our study to gain more insight into the relationships within the digital business ecosystem consisting of various companies, dealers and the users. Most of our interview partners were directly involved in commercializing digital tools within their organization. In addition to these managers stemming from corporates or start-ups, we included another group of experts, namely (8) consultants and industry associations reflecting a meta-perspective on different actors' strategies in the emerging digital agricultural ecosystem. All interview partners were German. Hence, the main point of view was the European market, although our experts were mainly working for multinational companies (see appendix Table A7 for more details).

Interviews were conducted via Zoom between September and December 2021. The interviews lasted between 30 min and 1.5 h. A basic questionnaire (see appendix Table A8) was used to conduct semi-structured interviews focused on some professional information of the interviewee; the company's business model (original and impact of digitalization); the firm's position in the ecosystem (perception of new entries, valuable resources in the ecosystem and the role of value networks); the bargaining situation (awareness of conflicting interests within the ecosystem and influencing factors on company's profit); the perception of the firm's sustainable competitive advantage (uniqueness and isolating mechanisms) and ultimately some general dynamics within the agricultural industry. Depending on the interviewee, questions were adapted to the context and origin of the firm. In the end, we conducted interviews with 15 companies (including one consultancy, one industry association and one farmer). Additionally, we triangulated our interview data by including secondary data (i.e., company websites and news reports) to provide background information on the firms and interview partners and the business model evolution.

4.3.3 Data analysis

A first screening of the interview data was done using the analytical dimensions according to the interview guideline (see Table A8). This step helped in structuring our data and identifying missing information, which were subsequently gathered by further desk research. The actual data analysis was performed using the qualitative methodology following suggestions by Gioia,

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[5] It should be mentioned, that specialists were not directly part of our multiple-case study. However, since our interview partners often referred to established niche players, i.e. specialists, producing for instance highly customized equipment while reacting fast to customer requirements in comparison to large equipment manufacturers who need to serve global needs, we subsequently included them as an actor type in the digital agricultural business ecosystem.

Corley, and Hamilton (2013). The interview data revealed how companies strategically respond to the changing business environment and position themselves in the digital business ecosystem. As stated in section 2.2, we assume that positions revealing a certain bargaining power manifest themselves in digital business ecosystems through control points.

Accordingly, we restrict the data analysis to control points within the interview data and first, inductively derive first order codes that closely represent our raw data (Gioia, Price, Hamilton, & Thomas, 2010). In this step, the authors read through the interview transcripts and coded statements they believed to be relevant. A subsequent iterative process involving many discussions among the authors led to 40 first order codes.

In a second step, first order codes were assigned to seven second-order themes *content, modularity, digital infrastructure, orchestration, networking, customer access* and *brand.* These second order themes represent control points as laid out by Pagani (2013) and Van Dyck et al. (2021). However, as not all first order codes could have been assigned to the predefined second order themes, we analyzed the remaining first order codes according to similarities and differences (Gehman, Glaser, Eisenhardt, Gioia, Langley, & Corley, 2018) and grouped them into eight new emerging second-order themes (Gioia et al., 2013).

In a third step, the 15 second-order themes were aggregated into three overarching dimensions: technical and strategic control points and a new dimension that emerged, namely institutional boundaries. In line with Gioia et al.'s (2013) methodology, Figure 4.4 represents the data structure that emerged from the analysis of control points within digital business ecosystems. We used the data structure to assess the relationship between different control points and to evaluate which strengths the actors in our case study reveal in the different types of control points. In total, we generated ca. 230 pages of transcripts, which were analyzed using the software MAXQDA.

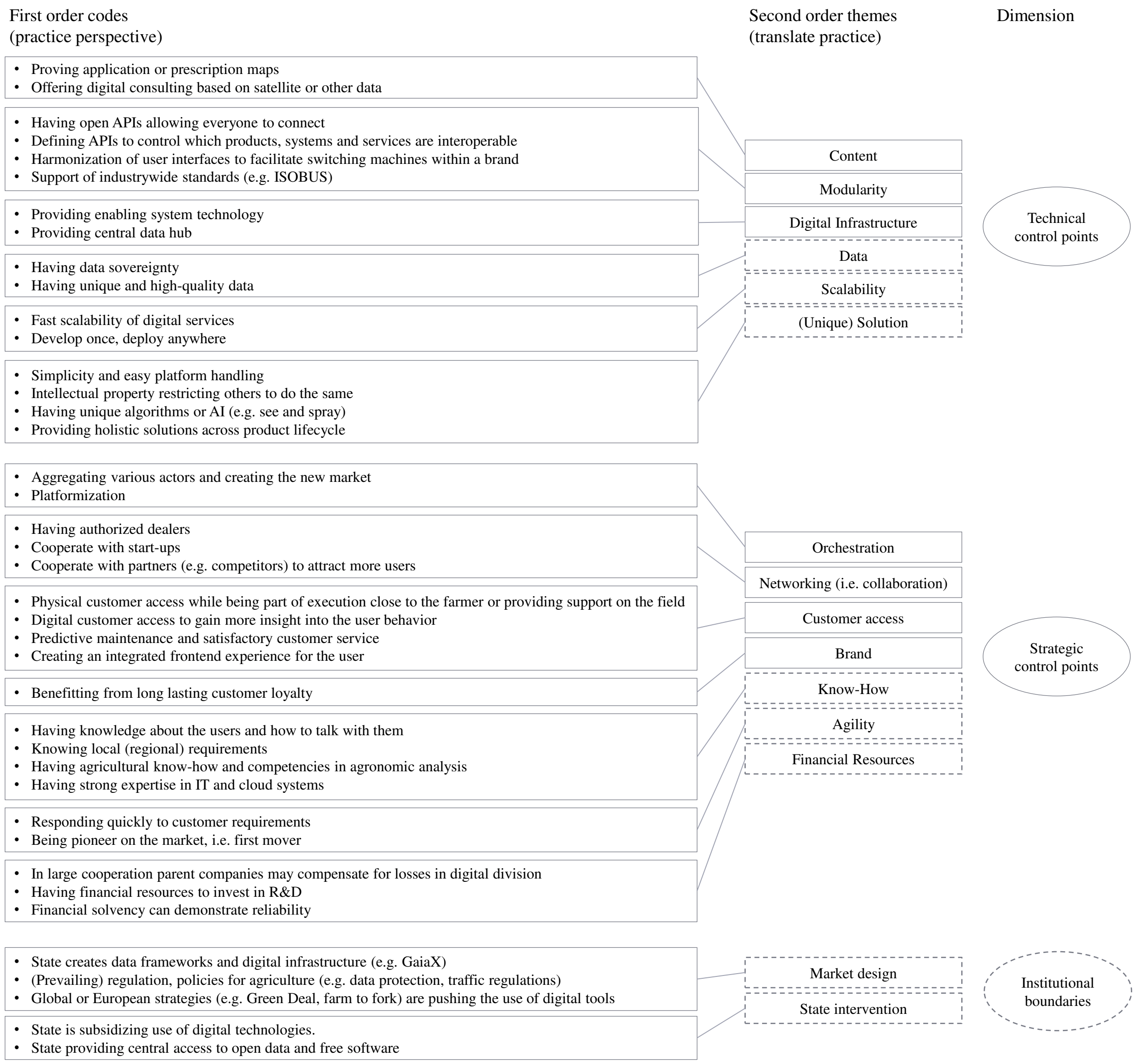

Figure 4.4: Data structure.

Remark: Second order themes or dimensions framed by continuous lines have been predefined in literature, whereas second order themes or dimensions framed by dashed lines have emerged inductively from our data.

In a fourth step, we conducted the within- and cross-case analysis (Eisenhardt, 1989). The within-case analysis helped to understand the role of individual control points and led to the definition of different types of control points and institutional boundaries. For the cross-case comparison, we used the strategic groups defined in 3.2. They are characterized by similar control point patterns. However, we only included corporates or start-ups in the cross-case analysis and left out farmers and consultancies for this analysis due to the difficulty of comparison. We conducted the comparison based upon the occupation of control points and checked which control points belong to the respective strategic groups.

4.4 Results

4.4.1 Control points in digital business ecosystems

To understand how companies position themselves within an emerging digital business ecosystem, we analyzed the interview data and derived two different dimensions of control points. The first dimension relates to *technical* control points that resemble firm resources inherent in technology. They comprise technical solutions including property rights that enable or restrict access to the digital business ecosystem (Van Dyck et al., 2021). By contrast the dimension of *strategic* control points resembles firm resources being characterized as soft not physically tangible inherent in the organization. Further, we identified *institutional boundaries*, which have a positive or negative influence on control points. Hence, institutional boundaries set the external conditions for the digital business ecosystem and the firm-created control points to unfold their value creation and capture potential.

In total, the within-case analysis led to the identification of six technical control points within digital business ecosystems, including (1) *content*, (2) *modularity*, (3) *digital infrastructure*, (4) *data*, (5) *scalability* and (6) *(unique) solution*, and seven strategic control points including (7) *orchestration*, (8) *networking*, (9) *customer access*, 10) *brand*, 11) *know-how*, 12) *agility* and 13) *financial resources* as well as two institutional boundaries including 14) *market design* and 15) *state intervention*. Table A9 in the appendix provides an overview including brief descriptions of the control points and institutional boundaries.

The meaning of the control point *content* is rather self-explaining and refers to the ability or resources to offer valuable content, such as digital decision support or digital consulting based on satellite data to the end-user. Thus, a critical success factor in achieving or holding a sustainable competitive advantage is to be able to control the *content* within the digital business ecosystem to eventually become a content gatekeeper (Pagani, 2013). Dealer A is seeking to occupy this control point:

> *"And we are also a producing company in certain areas - now in terms of software. We have developers, who produce information systems. Or, as I said, [our subsidiary], which produces digital advice based on satellite data, other data and plant growth models, and makes appropriate fertilizer recommendations for agricultural machinery."* (Dealer A)

The control point *modularity* refers to the compatibility with other players to be able to connect different machines and digital tools and thus connect to more value creating sources. Value relies in creating modules that can be integrated in many different machines, systems or platforms. Companies want to widely spread their capabilities rather than protect them as proprietary assets (Pagani, 2013). For example, defining APIs to control which products, systems and services are interoperable or the support of industrywide standards (e.g., ISOBUS) are considered as *modularity.* Accordingly, chemical company B said:

> *"So, we are basically open, we have our own interface where partners can connect. An API is publicly accessible, and that's no secret. In this regard we are open."* (Chemical company B)

The control point *digital infrastructure* creates value by reducing distribution, transaction, and search costs when different actors come together (Pagani, 2013). Examples are providing enabling system technology or providing a central data hub. The interviews revealed that a company holding this control point especially creates value for digital service providers, as it becomes more cost-efficient and predictable to deliver digital support and control actual outcome. As potentially all actors need to use this technology to participate in the ecosystem, there is a huge potential for value capture.

> *"[...] Accordingly, we said, "Okay, dear digital service provider, it's clear that you're going to [the big machine manufacturer] if he already has [the infrastructure]. And for the others, [...], we offer an alternative or mixed fleet, i.e., [brand A] tractor with [brand B] field sprayer or something like that. So, we're standing there and we're kind of building the android [for the agricultural industry]."* (Technology provider)

The control point *data* encompasses the technical resources to generate, own or provide data in the digital business ecosystem, like e.g., having data sovereignty or having unique and high-quality data. *Data* allows access to information and knowing how to create valuable insights from it, like e.g., analytics or big data. Thus, value is created by summarizing, holding and evaluating data in a central location. As many actors within a digital business ecosystem potentially have to pass this control point, there is a significant potential for value capture, as the software provider said:

> *"The greatest value emerges if I can summarize, hold and evaluate the data in a central location."* (Software provider)

The control point *scalability* refers to a firm's technical resources to build a scalable business model (in the future). It is the capacity to increase output at decreasing marginal costs. Having a product or process which is scalable lead to increasing value capture in the future. For instance, for digital service providers, this control point might be enabled by the availability of an appropriate *digital infrastructure* within the digital business ecosystem in which the company operates. The technology provider referred to *scalability* while responding:

> *"We cut all machines at the bottom and separate functions from machines. This means "develop once, deploy anywhere". This is an old Java saying, which means that the*

> *marginal development and sales costs tremendously decrease [...].”* (Technology provider)

The control point *(unique) solution* encompasses either a technical solution restricting other ecosystem participants to do the same (e.g., intellectual property) or enabling a unique benefit at the customer front-end or across the product life cycle. It satisfies an unmet need more efficiently or at higher value, e.g., user experience, than competition or alternatives. Thus, value is created by unique features and value is captured by customers appreciating unique products and services. Start-up A is for instance seeking to hold this control point in identifying a farmer’s specific field boundaries by using satellite images:

> *“We have our own algorithm that can do that, well, I'll say optimistically nine times out of ten.”* (Start-up A)

The strategic control point *orchestration* refers to a company’s strategic position being able to coordinate between modules and various actors across value chains and industries. With increasing modularization, this ability becomes highly valuable for creating a common EVP and hence obtaining a central ecosystem position (Pagani, 2013). The technology provider referred to it:

> *“We have to be neutral and open to all players, so that everyone has confidence in us. And none of the players will develop the market themselves, but the orchestrator will have the difficult task of first creating the market, then bringing the players to the table, then motivating the players, and then pampering them so that they join in.”* (Technology provider)

Networking is a control point that reflects the ability to establish the “right” connections to partners and also competitors to guarantee participation in the digital business ecosystem game (Dattée et al., 2018; Van Dyck et al., 2021). Hence, being able to create alliances of value creation or capture.

> *“[...] strategic partnerships that are developed. That means sitting at the table with the right people and then getting the chance to establish your product or service. Because in the end, many small companies do something. They all offer a service somehow. And that works on a small scale. But how can it be integrated into the big playground? And for that you need a partner who allows it. And if it then works, then it is also accepted. And I think there is a hurdle. How do I get in to this door?”* (Start-up A)

The *customer access* control point refers here to the direct end-customer access, i.e., direct access to the farmer in the case of the digital agricultural business ecosystem. In digital business ecosystems value is increasingly created at the end of the network, namely the customer. *Customer access* allows highly customized connections leading to value creation for and with the customer (Pagani, 2013; Van Dyck et al., 2021). *Customer access* includes physical customer access close to the farmer while being able to provide support on the field or digital customer access while providing access to digital platforms. Dealer A is addressing the relevancy of the physical *customer access*:

> *"Technical problems that have different causes have to be solved. In theory, this could be done remotely, but it's also a matter of trust. The farmer says "come when there's a problem". If this "digitization" is again not working, someone taking care of it is a huge factor."* (Dealer A)

The control point *brand* includes the existence or ability to establish a powerful brand reputation, as it leads to customer loyalty and potentially lock-in effects and potential for more value capture (Van Dyck et al., 2021). Having a control point on *brand* leads to being perceived as a trusted supplier:

> *"Some people love brand A, others brand B, next one other machine manufacturers. In this case, love means trust. And I believe that once they are with one of them, they will stick with it."* (Consultancy)

Know-how encompasses various layers of expertise, which are necessary to compete in the digital business ecosystem. It is important that companies are aware of their respective expertise and know how the market of the emerging digital business ecosystem works. For example, having knowledge about the users and how to talk with them or having agricultural know-how and competencies in agronomic analysis. Start-up A referred to its control point in *know-how* in technology while claiming:

> *"Yes, our resources are of course that we are a spin-off from companies that just have very, very good tech potential [...]."* (Start-up A)

The control point *agility* encompasses spotting and creating new value creating sources faster than competition. It refers e.g., to the strategic decision to be early in investing in R&D advancing digital technologies or being agile in reacting to customer requirements eventually protecting or fostering a company's competitive advantage.

> *"And one issue is and this is definitely an issue also in our restructuring: we want to act faster and more customer-oriented."* (Manufacturer B)

The control point *financial resources* moderates all of the above control points to catch up or fast forward beating the competition. It allows a position within the ecosystem proving reliability to partners and having the flexibility to follow trial and error in trying for instance new and different markets.

> *"So [our company] is a very, very financially sound company. If the farmer does business with us, he can pretty much rely on the fact that he can also sell his used agricultural machinery back to us in 6 years or that he will get his grain money and so on."* (Dealer A)

Eventually, a new dimension of control on value creation and capture within digital business ecosystems has emerged in our study. This dimension relates to *institutional boundaries* and encompasses *market design* and *state intervention*, which are external conditions that moderate the value creation and capture potential. *Market design* refers to the institutional (competition law related) control to design the level playing field of a specific market. It includes e.g., data frameworks and digital infrastructure or (prevailing) regulations, policies for agriculture like data protection or traffic regulations in the case of digital agriculture. Prevailing regulations are set by institutions, which eventually may have an impact on the value creation and distribution among business ecosystem participants. The software provider for instance referred to the potential of setting the control point *market design* by saying:

> *"And yes, I am convinced that this central decision is needed. Whoever provides the technology at the end of the day is, again from my point of view, a decision that has to be made, but I believe that this central unit is needed because otherwise, we will see what I believe is already beginning to emerge. [...]. And at the end of the day, the public sector will have to accept what's there, because at the end of the day, it may simply be too late to set the agenda, as much has already been established in the market that you simply can't turn back certain things."* (Software provider)

The institutional boundary *state intervention* refers to the active institutional intervention, such as subsidies or data protection regulation, in the digital business ecosystem promoting the use of digital technologies and facilitating data accessibility. For example, the state is subsidizing the use of digital technologies or providing central access to open data and free software. The industry association said:

> *"The [German] coalition agreement states that there is to be an agricultural platform, a state platform at the federal level. That is what we have demanded by central access to services, a central access to open data and what is not included yet but is important would be to provide connection possibilities for software and IT services from companies."* (Industry association)

Summarizing, the within-case analysis of the individual companies' strategies had led to the identification of 13 control points and two institutional boundaries. To compare the different actors (cases) regarding which of these control points they possess and to derive different strategies, the following section provides a cross-case analysis.

4.4.2 Control point allocation in light of a cross-case analysis

The interviewed companies were previously aggregated into six strategic groups, which could be confirmed by similar control point patterns among individual strategic groups. That means, while referring in the paper to the "chemical company" or the "large equipment manufacturer", we do not necessarily mean a specific company, but rather a certain strategic group following a similar pattern in the digital agricultural business ecosystem. Table 4.1 illustrates that control points are unequally distributed among the strategic groups and layers within the modular layered architecture. Some actors have a stronger focus on strategic control points (strategic group 3), some on technical (strategic group 4 and 6), others on strategic and technical control points at the same time (strategic group 1, 2 and 5).

Strategic group 1, the large equipment manufacturer, combines strategic and technical control points. In total, it owns, however, even more control points covering the entire set of layers. Its focus is on connecting and orchestrating the different actors in the ecosystem (e.g., *digital infrastructure*), while using its *brand* reputation and *financial resources* to achieve exclusivity. Similarly, strategic group 2, the chemical company, owns most control points on the analytics and digital service layer. It reveals a balance of strategic and technical control points. It seeks to gain prominence within the digital business ecosystem through offering *modularity*, digital *content* and owning and analyzing valuable *data*. Strategic group 3, the dealer, has its most control points on the physical layer, whereas its focus is on *customer access* and providing *content*, i.e., consulting, to the farmer. However, the dealer has only a few technical control points and concentrates on strategic control points. Strategic group 4, the software provider, only holds control points on the analytics and digital service layer, whereas the major focus is on a few technical control points (e.g., *data* and *scalability*). Strategic group 5, the technology provider, uses its technical resources (control points) to strategically position itself in the ecosystem by taking the control points *networking* and *orchestration* to eventually create *customer access.* Although strategic group 6, the specialist / AgTech start-up, holds as many technical as strategic control points, its main focus is on technical control points. Through the strategic control point *networking* it seeks to connect to other ecosystem participants in order to offer open source access for specific components (e.g., *unique solution*, *modularity*). Whereas Table 4.1 reveals an accumulated overview of the control point distribution, the next section provides more insight into the control point evolution over time.

Table 4.1: Cross-case analysis

Strategic group	**Strategic / technical focus**	**Control Points on physical layer**	**Control Points on data sampling layer**	**Control Points on connectivity layer**	**Control Points on analytics layer**	**Control Points on digital service layer**
Strategic group 1 (Large equipment manufacturer)	**Focus technically + strategically: Orchestrator and investing in exclusivity**	Modularity (T) Data (T) Unique solution (T) Orchestration (S) Networking (S) Brand (S) Know-how (S) Agility (S) Financial resources (S)	Brand (S) Financial resources (S)	Modularity (T) Digital infrastructure (T) Unique solution (T) Orchestration (S) Networking (S) Customer access (S) Brand (S) Know-how (S) Agility (S) Financial resources (S)	Content (T) Modularity (T) Data (T) Scalability (T) Unique solution (T) Networking (S) Customer access (S) Brand (S) Know-how (S) Agility (S) Financial resources (S)	Content (T) Modularity (T) Data (T) Scalability (T) Unique solution (T) Networking (S) Customer access (S) Brand (S) Know-how (S) Agility (S) Financial resources (S)
Strategic group 2 (Chemical company)	**Focus technically + strategically: Digital leadership and data owner**	Unique solution (T) Networking (S) Brand (S) Know-how (S) Financial resources (S)		Unique solution (T) Customer access (S) Brand (S)	Content (T) Modularity (T) Data (T) Scalability (T) Unique solution (T) Networking (S) Customer access (S) Brand (S) Know-how (S) Agility (S) Financial resources (S)	Content (T) Modularity (T) Data (T) Scalability (T) Unique solution (T) Networking (S) Customer access (S) Brand (S) Know-how (S) Agility (S) Financial resources (S)
Strategic group 3 (Dealer)	**Focus strategically: Customer centricity and consultant**	Content (T) Unique solution (T) Orchestration (S) Networking (S) Customer access (S) Know-how (S) Financial resources (S)		Modularity (T) Networking (S)	Unique solution (T) Customer access (S) Know-how (S)	Content (T) Unique solution (T) Customer access (S)

Strategic group 4 (Software provider)	**Focus rather technically: Digital leadership**				Content (T) Unique solution (T) Know-how (S) Agility (S) Financial resources (S)	Content (T) Data (T) Scalability (T) Unique solution (T) Agility (S) Financial resources (S)
Strategic group 5 (Technology provider)	**Focus technically + strategically: Orchestrator and enabling agility + scalability for all actors in the ecosystem**	Networking (S)	Modularity (T) Digital infrastructure (T) Unique solution (T) Agility (S) Financial resources (S)	Modularity (T) Digital infrastructure (T) Scalability (T) Unique solution (T) Orchestration (S) Networking (S) Know-how (S) Financial resources (S)		Content (T) Data (T) Customer access (S)
Strategic group 6 (Specialist / Ag-Tech start-up)	**Focus rather technically: Open source access for specific components**	Unique solution (T) Agility (S)		Networking (S)	Content (T) Modularity (T) Unique solution (T) Know-how (S) Agility (S)	Modularity (T) Unique solution (T) Know-how (S) Agility (S)

4.4.3 Control point evolution from physical product-oriented business models to emerging digital business ecosystems

By means of the interview data and additional secondary data sources, we show the temporal evolution, clustered into 3 phases, of control points within the digital business ecosystem, where different actors on different layers contribute to the ecosystem value proposition (EVP). The interviews reveal that the use of digital technologies enables new opportunities for value creation leading to the emergence of a digital business ecosystem. Figure 4.5 provides an illustration of this evolution. The top of Figure 4.5 shows the control points we identified in our multiple-case study summarized into three control point portfolios. The bottom of Figure 4.5 aggregates the value which each strategic group is contributing to the EVP and shows a weighting of the layers reflected by varying thickness.

Figure 4.5: Evolution of control point portfolio over time.

Remark: VP stands for "Value Proposition", whereas EVP stands for "Ecosystem Value Proposition". In phase 1, in non-digital ecosystems being dominated by vertical value chains, value generation is achieved by control of physical assets (resources). As a consequence, value propositions for the user are created by individual actors. Phase 2 and 3 reveal a digital business ecosystem perspective, where multiple actors on different layers contribute to the overall EVP. The different circle sizes in the upper half of the figure indicate the relative impact of an individual control point on the EVP. A small impact, for instance, means that there is a low potential for value creation and consequently value capture. The varying thickness of the circles in the bottom half of the figure illustrate the growing value share towards the upper layers (i.e., digital service) of the layered modular architecture.

In phase 1, there are only control points on the physical layer. Thus, there is no interaction between the physical and digital world and thus, no joint value creation. In this phase, we assume a linear value chain, where actors individually create VPs for the user in the physical world. *Customer access* or *content* (i.e., personal consulting) are major control points of the dealer, whereas *agility* is the main control point of specialists or start-ups. The chemical company and the integrated large equipment manufacturer share the control point *brand*, as they have built-up strong customer loyalty already. The technology provider holds a *unique solution* and a small share in the strategic control point *networking* to build up the fundament for its future positioning in the digital business ecosystem. In contrast, the software provider does not have control points in phase 1. Institutional boundaries (not illustrated in Figure 4.5) encompass e.g., general regulations or political agricultural frameworks. Control points, such as *modularity*, *digital infrastructure*, *data* and *scalability* are not yet relevant in phase 1 and only emerge with the advent of digital technologies.

In phase 2, the current situation, the EVP can for instance be *'providing a holistic solution throughout the product lifecycle'*, which was mentioned by manufacturer B in our interviews or *'ensuring a more sustainable and efficient farming system'*, which is the overarching goal of precision farming (Miranda et al., 2019). However, this can only be achieved if actors collaborate in digital business ecosystems, where actors hold different control points on different layers. Phase 2 shows that with the emergence of precision farming and digital technologies, new control point categories (e.g., *data*, *digital infrastructure*), new positions of control points on multiple layers and a new relevancy of individual control points emerge. For instance, the technology provider has a strong position on the data sampling layer, as it contributes sensors, which can be attached to other machinery (physical product layer). However, the technology provider only has a minor share in the digital service layer. In contrast, the chemical company transforms towards a digital service provider. It lacks the control point of physical *customer access* but seeks to leverage its position while fostering digital access to the user and providing open interfaces for e.g., machine manufacturers (*modularity*). A strength also relies in its control point of having *know-how* (e.g., analytical and agronomic expertise). Thus, it compensates its losses on the physical product layer (i.e., chemical input is reduced by higher efficiencies due to digital tools) by setting *content*, *modularity* and *data* control points on the analytics and digital service layers. The general vision among the chemical companies we interviewed is the shift of their business models from traditional linear ones (selling physical inputs) towards service-oriented business models. By integrating various data sources, such as weather or satellite data, the chemical companies increasingly provide precision recommendations to the farmers and even guarantee certain yields.

Through digital *customer access*, companies gain deeper inside into the users' behavior and hence try to leverage their future bargaining position. In addition, firms, such as a vertical integrated agricultural equipment manufacturer (B) hold strong and highly valuable control points in *digital infrastructure* and *orchestration* on the connectivity layer and hence, foster their own ecosystem while collaborating with selected partners on their platform. Having invested heavily in R&D to improve digital technologies for two decades, manufacturer B is now in a position to provide the infrastructure itself to ensure connectivity between its own and selected third-party machines and digital services. Referring to this actor's control point pattern, the technology provider said:

> *"And there are others, too, and the others now have a problem because they realize that even the largest, even the second largest, no longer has the capacity to set up something like [the huge agricultural equipment manufacturer] because they simply no longer have this market power."* (Technology provider)

The software provider now also holds control points in e.g., *scalability*, a*gility* or *content* on the analytics and content layers in the digital agricultural business ecosystem to which he refers as follows:

> *"[It] is the same platform worldwide, which exists only once. It also runs centrally via our global network. [...] what we provide with the platform is that regional or country-specific partners can dock onto the platform, which then again fulfill specific requirements of the respective region of the respective country."* (Software provider)

Specialists and AgTech start-ups increasingly join forces with other manufactures (i.e., *networking*) and seek to be interoperable and ensure connectivity, while offering open access (i.e., *modularity*). The dealers also integrate digital technology while offering farm management systems and including an e-commerce business model (i.e., *customer access* and *content*). As open data and connectivity are increasingly relevant, public institutions are also engaged in creating common standards (i.e., *market design*) to facilitate connectivity or gathering and providing data (i.e., *state intervention*).

Phase 2 can be summarized as the emergence phase of the digital business ecosystem where value creation is increasingly performed jointly by different actors and where all actors seek to possess control points on the digital layers, as their relative share in value creation increases. However, currently uncertainties due to missing dominant designs and standards directing to a lack of interoperability across different physical products and digital services are still a challenge, which certain actors seek to address.

Eventually during the transition towards phase 3, with an increasing amount of data and an increasing relevance of cloud computing, IoT and institutional changes, the existing control points in the digital world as well as control points on the connectivity layer gain even more relevancy. In addition to the current EVPs the claim of '*better interoperability'* will become even more important to address the shortcoming of the current system. Accordingly, in phase 3, the relevancy of certain control points (i.e., *content*, *modularity*, *digital infrastructure*, *data*, *orchestration*, *customer access* and *agility*) to realize the common EVP is increasing. Whereas in phase 2, the vertically integrated manufacturer is the main orchestrator and enabler of connectivity by providing *digital infrastructure* for own machines as well as external machines and services connected to its platform, in the future the technology provider will take a notable share of this orchestrator role. It is already setting major control points on the connectivity layer (i.e., *modularity*, *digital infrastructure* and *orchestration*) to ensure manufacturer independent interoperability. Subsequently, it collects *data* and gains *customer access,* as it creates interfaces to various actors in the digital business ecosystem and the end user, i.e., the farmer, who needs to buy a special devise in form of a small box to benefit from the infrastructure. The value of the technology provider's control point pattern is particularly evident for the digital service providers (e.g., App developer; precise decision support). The digital service providers currently face the problem of high development costs to guarantee the infrastructure allowing them to offer the service and to guarantee the correct execution of the recommendation given to the farmer. That means, often digital support is delivered to the farmer and he has to execute this recommendation manually on its machines, as the connection between the digital service provider and the manufacturer is not provided. That also complicates the quality management of the digital service provider. The technology provider responded:

> *"And then there's the big question of what it will cost me to develop and maintain this service. And in the digital sector in particular, it is actually the case that you have relatively high jump costs to implement a technical solution. And if you then want to scale it across many, many different things and also in the different countries, then it becomes expensive very quickly. And from my point of view, that prevents the market from really pushing innovations forward, because there are individual solutions that only scale moderately."* (Technology provider)

Also, the software provider is striving to occupy new control points in phase 3. Consequently, especially the dealer will lose some share of its control points.

Summarizing, we show that, with the emergence of precision farming and digital technologies, first, new control point categories (e.g., data, digital infrastructure), second, new positions of control points on multiple layers and third, a new relevancy of individual control points emerges. The control point portfolio evolution shows that the “pie” is growing over time.

On the one hand, we assume that additional value to the ecosystem is added layer by layer. On the other hand, we anticipate that the value of individual layers (e.g., connectivity or digital service) will grow in the future, whereas the value relying on the physical product layer will shrink. Referring to these assumptions the large equipment manufacturer B reported:

> *"Against the backdrop of digitization and data processing and the gold of today, namely data, the actual machines are just accessories and become - to put it drastically - just a means to an end."* (Manufacturer B)

That means, upper layers contain a larger potential to contribute to the EVP and thus, for actors to create and capture value in the end. Hence, actors should seek to acquire control points on these layers. Our interview data suggest that the distribution of value on the digital layers will be divided almost equally between technology providers, machine manufacturers, chemical companies, and software providers.

4.4.4 Control point strategies

Based upon our cross-case analysis we observed that the actors involved pursue three different strategies. Notably, the strategic groups ‘distributors’, ‘chemical companies’ and ‘equipment manufacturers’ originally all pursue a similar strategy. Their core business is physically oriented. A similar pattern could be observed within and in between the remaining strategic groups. Accordingly, we derive the following three generic control point strategies based upon different ‘going-in positions’, which characterize an actor’s original position and market focus, *(1) analog to digital, (2) digital entrant and (3) lateral entrant* (see Table 4.2).

Actors starting with the ‘*analog to digital’* going-in position into the digital agricultural ecosystem include the large equipment manufacturer, the chemical company, and the dealer. They are strong on the physical (product) layer in phase 1 (i.e., they had already a significant stake in the agricultural industry). To address the growing importance of digital technologies, these actors occupy control points on the digital layers in phase 2. They pursue their strategy by, e.g., focusing on the development of digital twins allowing agility as they enable the digital representation of machinery and hence, predictive maintenance and performance improvements (Parmar, Leiponen, & Thomas, 2020). Additionally, many ‘analog to digital’ actors strive to move towards offering farm management information systems and entire solutions, i.e., solutions across the product-life cycle (Verdouw, Tekinerdogan, Beulens, & Wolfert, 2021). As this going-in position is characterized by actors possessing numerous control points on all layers across the layered modular architecture, it could also be related to vertical integration as a possibility to remove bottlenecks and to manage ecosystem interdependence (Adner & Kapoor, 2010; Hannah & Eisenhardt, 2018). Obviously, actors within the 'analog to digital' group differ in terms of the extent of individual control points. However, all players pursue the approach of setting control points on the digital layers in addition to the ones they had already in phase 1 on the physical layers. Due to their long history in the agricultural industry, these actors share a strong brand reputation and customer loyalty by possessing control points in *brand* on all five layers.

The ‘digital entrant’, especially referring here to AgTech start-ups, moves into the emerging digital business ecosystem by solely attacking control points on the digital layers. This going-in position is characterized by little own (financial) resources, but offering *unique solution, modularity* and *content* on the digital layers. Accordingly, they are able to achieve *agility* on the analytics and digital service layers. The ‘digital entrant’ occupies niches of the emerging digital business ecosystem while contributing components, such as unique assessments of crops and soils to the overall EVP. It is noticeable that the first two strategies reveal little changes in control point occupation from phase 2 to 3. The strategies’ focus is rather on expanding existing ones with an emphasis on expanding control points on the digital layers.

Furthermore, we identified digital infrastructure as well as the interoperability of different machines as a bottleneck in creating value in the emerging digital business ecosystem. ‘Lateral entrants’, such as the technology provider and the software provider can be aligned to the bottleneck strategy (Hannah & Eisenhardt, 2018; Jacobides et al., 2018). These actors have already a strong position, i.e., own valuable control points, in their old industries. In phase 2 and 3 they seek to attack the digital agricultural business ecosystem as lateral entrants occupying control points on data sampling and connectivity layer. In the future, the ‘lateral entrant’ is seeking to gain an orchestrator role in the emerging digital business ecosystem and eventually own control points in *content* and *data* enabling them to offer unique solutions also on the analytics and digital service layer.

Table 4.2: Generic control point strategies.

	Control Point / Going-in position	**Analog to digital**		**Digital entrant**		**Lateral entrant**	
	Strategy	*Defend traditional position and add new position*		*Provide unique value-added services on individual layers*		*Provide infrastructure*	
		Phase 2	Phase 3	Phase 2	Phase 3	Phase 2	Phase 3
Technical	Content	●○○🟢🟢	○○○●●	○○○🟢○	○○○●🟢	○○○○○	○○○🟢🟢
	Modularity	●○🟢🟢🟢	●○●●●	○○🟢🟢🟢	○○●●●	○🟢○○○	○●🟢○○
	Digital Infrastructure	○○🟢○○	○○●○○	○○○○○	○○○○○	○○🟢○○	○●🟢○○
	Data	○○○🟢🟢	○○○●●	○○○○○	○○○○○	○○○○○	○○○🟢🟢
	Scalability	○○○🟢🟢	○○○●●	○○○○○	○○🟢🟢🟢	○🟢○○○	○●🟢🟢🟢
	(unique) solution	●○🟢🟢🟢	●○●●●	○○○🟢🟢	○○○●●	○🟢🟢○○	○●●🟢🟢
Strategic	Orchestration	●○🟢○○	●○●○○	○○○○○	○○○○○	○○🟢○○	○○●○○
	Networking	●○🟢🟢🟢	●○●●●	○○○🟢🟢	○○○●●	●○🟢○○	○○●○○
	Customer access	●○🟢🟢🟢	●○●●●	○○○○○	○○○○○	○○○○○	○○○○🟢
	Brand	●🟢🟢🟢🟢	●●●●●	○○○○○	○○○○○	○○○○○	○○○○○
	Know-how	●○🟢🟢🟢	●○●●●	○○○🟢🟢	○○○●●	○🟢🟢○○	○●○🟢🟢
	Agility	○○🟢🟢🟢	🟢○●●●	○○○🟢🟢	○○○●●	○🟢○○○	○●○🟢🟢
	Financial resources	●🟢🟢🟢🟢	●●●●●	○○○○○	○○○○○	○🟢🟢○○	○●●🟢🟢
	Focus	- Digital Twins - Vertical integration		- Modularity - Agility		- Bottleneck	
	Strategic groups following these strategies	- Large equipment manufacturer - Chemical company - Dealer		- Specialist / AgTech start-up		- Software provider - Technology provider	

Remark: In phase 2 and phase 3, the five circles in the actor columns represent the five layers of the layered modular architecture. If a circle is filled, that means the actor possesses the control point on the respective layer. For instance, in P2 an actor in the 'analog to digital' column possesses the control point content on the physical, analytics and digital service layers. Green circles mark when a new control point set. In addition, it should be noted that this table only considers technical and strategic control points, as they are proactively set by companies, whereas institutional boundaries are rather shaped by companies and are eventually set by institutions.

4.5 Discussion

4.5.1 Relationship between technical and strategic control points and institutional control boundaries

Figure 4.6 provides an overview of the relationship and interplay between technical and strategic control points to contribute to the EVP while being influenced or restricted through institutional boundaries.

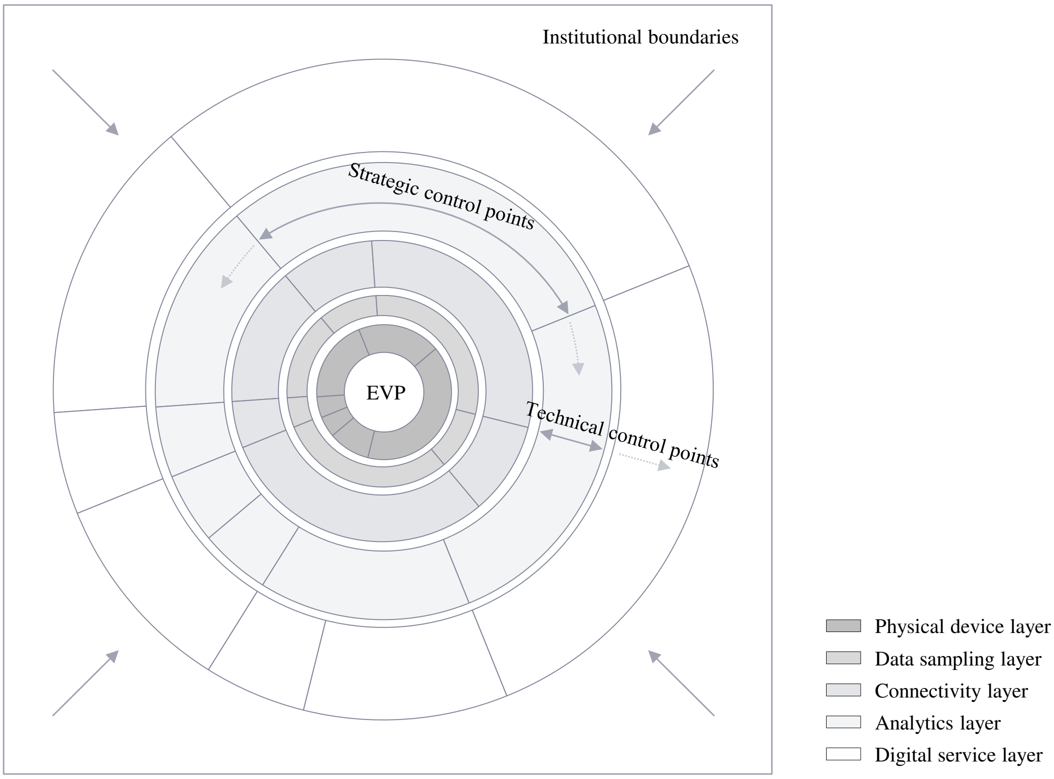

Figure 4.6: Relationship between technical and strategic control points and institutional boundaries within a digital business ecosystem.

First, we argue that technical control points within the digital business ecosystem are needed to gain a certain position on any layer. These control points can directly lead to a product or a business model and are a necessary condition to create perceived value at all. *Technical control points* are much more dynamic as if they were considered by the RBT, as they particularly allow to connect with other actors and co-create value across different layers to form a joint value proposition.

Second, we propose that *strategic control points* are primarily used to increase an actor's bargaining power (i.e., value capture potential) vis-à-vis direct competitor within the layer and thus an actor's share horizontally. Accordingly, we consider strategic control points as rather long-term oriented to achieve a positioning within a layer. We suggest that strategic control points are needed to expand technical control points even further. In some cases, these are even necessary in order to participate in the EVP at all (e.g., *know-how*). This, however, does not necessarily apply to all strategic control points. For example, *orchestration* is not expected from all actors and cannot be provided by all as shown within the different control point strategies (see section 4.4). The same applies to *brand*. In order to increase a technical control point (e.g., *modularity* or *data*), strategic control points, such as *know-how* are necessary.

Some control points, such as *financial resources*, *brand* or *know-how,* are also rooted in the RBT (Barney, 1991). Our results reveal that they are still relevant in an emerging digital business ecosystem when explaining competitive advantage. In contrast, strategic control points, such as *orchestration* and *networking* are much more dynamic than valuable resources described in the RBT (see Barneys VRIN framework). In a similar vein, technical control points are much more dynamic as if they were considered by the RBT, as they particularly allow to connect with other actors and co-create value across different layers. Also, it is important to connect to the "right" partner. That means, in contrast to IO informed market base view (i.e., positioning school) rooted in the seminar work of Porter (1981), considering other competitors not as a thread but rather as a potential to create future common value.

Third, we propose that *institutional boundaries* (*state intervention* and *market design*) have an influence on companies' technical control points since they set the external boundaries and moderate the value creation and capture potential. Institutional boundaries can be also considered as triggers leading to dynamic changes of business models, i.e., towards setting particular control points (Trossen, 2005). Interviews reveal that there are plans for government platforms offering publicly accessible data.

4.5.2 Discussing control point relevancy

A company needs to align its strategy or competitive position with its internal resources and capabilities in relation to external opportunities. However, in contrast to the market-based view and the RBT, in an era of emerging digital business ecosystems, where industry boundaries are blurring and resources are shared among ecosystem participants to create greater EVPs, there is a need for more dynamic concepts such as the control point analogy we derived in the paper. In line with the RBT, where not all resources are of equal importance (Prahalad & Hamel, 1990), control points are not of equal importance either.

Thus, *orchestration* or *data* are for instance highly valuable control points, whereas *financial resources* are indeed necessary to contribute to the EVP, but do not directly contribute to high value creation or capture in the digital business ecosystem. Some control points are stronger in setting the direction for value capture (e.g., *orchestration*), others are stronger in value creation (e.g., *content*) (Van Dyck et al., 2021). There are control points which only influence value for the end-customer. For instance, the control point *content* (e.g., digital decision support for the farmer, providing more precise and efficient farming) creates value for the end-customer but not directly to any other actor within the ecosystem. Depending on how many actors a technology can connect, the stronger is the control point. Thus, the control point of having an enabling technology by providing the *digital infrastructure* for all other participants leads to great value creation for other actors, as for instance their developing costs are reduced or connectivity is guaranteed. Since this control point can also be considered as a bottleneck for any actor striving to participate, there is a huge potential for value capture for the control point holder by generating revenue streams through e.g., pay per use business models. Accordingly, the actor holding the control point creates a certain dependency for other ecosystem participants and acts as a bottleneck (Hannah & Eisenhardt, 2018).

We believe that control points on the digital layers are particularly relevant in contributing to the perceived value in the digital business ecosystem. In contrast to the high value of digital layers claimed in the paper it has to be remarked that the customer currently sill primarily pays for the physical product, such as tractors or wheat. Machine manufacturer A summarized the dilemma as follows:

> *"In the end, the added value comes from the ton of wheat that is produced, transported and sold. And whether I do it via digital farming or not, it's only a few percent in the value added. There is a misconception in all politics and in research funding that people are thinking far too early that just because I am now a digital farmer, my value added will change."* (Manufacturer A)

However, we assume that in total more actors are interested in participating in the digital business ecosystem. Hence, more value might be potentially created. Also, digital technologies (precision agriculture) should lead to higher yields on the field. Accordingly, we still claim that the value mainly relies on the digital layers, as higher yields will be mainly caused by higher value creation on the digital layers.

Not all control points are easily occupied by all actors and it is not desirable. That means, depending on the company's original path, having either a strong technology or strategic focus, it might be easier or more difficult to set new control points across the multi-layer architecture of the digital business ecosystem. Specialists and AgTech start-ups need special control points, such as *unique solution* or *agility* to gain a competitive advantage. In line with Iansiti and Levien (2004), keystone players, such as large integrated equipment manufacturers approach the niches while offering or forcing niche players to incorporate their products into the orchestrator's platform.

As it is challenging to coordinate (interfirm) *modularity* that may increase interdependencies between ecosystem actors, companies are advised to manage interdependencies (Staudenmayer et al., 2005) through for instance fostering common standards or lobbying towards a desired *market design*, which was also reported in our interviews. In the past and today, public authorities have contributed only little to the overall EVP. The interviews, however, revealed that the role of public authorities (i.e., policy) may become more relevant in the future, as they might be responsible for harmonized data structures and digital infrastructures as well as providing certain data and services for free.

We could show that control points reflect a certain *technology-strategic perspective* on strategy and competitive positioning in the digital age. That means, in order to gain and keep a competitive position, capturing a remarkable share of the total value, in a digital business ecosystem, companies always need to combine strategic and technical control points. The resource / capability set seems to influence which control points are accessible and deployable (Barney, 1997). Thus, depending on whether a company originally had a strong technology or strategic focus, it might be easier or more difficult to set new control points across the multi-layer architecture of the digital business ecosystem. For companies with a strong technology focus, it might be easier to capture technical control points in the digital world. However, they need to consider strategic control points at an early stage of an emerging digital business ecosystem, in order to increase and sustain its bargaining power.

4.5.3 Discussing control point strategies

Figure 4.7 presents the control point strategies aligned with the layer perspective. Moreover, it contains the most relevant control points for the respective strategy. The 'lateral entrant' has been described as the bottleneck strategy. It has to be remarked that the large equipment manufacturer B (sorted among the 'analog to digital') might also be a bottleneck for the emerging digital business ecosystem. However, the main focus of the 'lateral entrant' are control points on the connectivity layer. That is why it is stronger related to the bottleneck strategy than the 'analog to digital' actor group. Further, it should be critically reflected that there are differences within strategic groups as well as within generic strategies. For instance, the chemical companies (A to C) from our interviews do not all have the same strength on the digital layers. Accordingly, control points are of varying relevance for companies of the same strategic group, because the companies have different capacities or pursue slightly different strategies. However, all actors from this strategic group seek to occupy control points on digital layers.

In the future (phase 3), with an increasing amount of data and an increasing relevance of cloud computing, IoT and institutional changes even more control points emerge and control points in the digital world as well as control points on the connectivity layer gain even more relevancy. The role of public authorities (i.e., policy) may become more relevant in the future, as they might be responsible for harmonized data structures and digital infrastructures as well as providing certain data and services for free. Hence, the public authorities' share on the digital service layer increases.

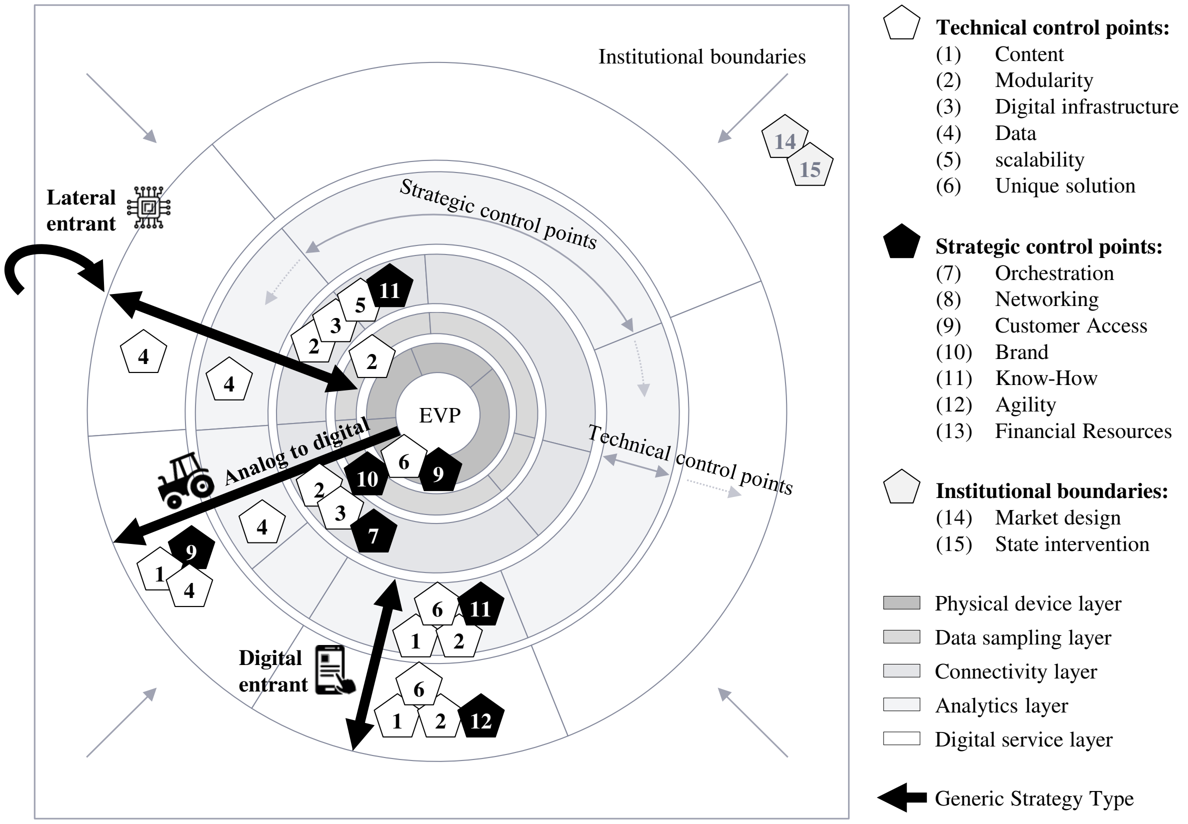

Figure 4.7: Control point strategies aligned with layer perspective.

4.6 Conclusion

In this paper, we combine the concepts of digital business ecosystems and control points being determined and shaped by their unique positions, unique resources and the institutional context, influencing the possibility to create and capture value today and in the future within an ecosystem. We build upon a multiple-case study within the agricultural industry and identify 13 control points as well as two institutional boundaries. Subsequently, we develop a control point portfolio and show its evolution over time. Our research was motivated by the question how companies position themselves to achieve bargaining (market) power and a sustained competitive advantage in an emerging digital business ecosystem. Accordingly, we derive generic control point strategies how different actors depending on their going-in position create competitive advantages vis-à-vis other actor in the emerging digital business ecosystem. Within digital business ecosystems, the competitive advantage does not solely rely in the company's own resources, but rather in the company's ability to connect to other actors and to complement own resources, while eventually contributing to the EVP. The framework of control point portfolios developed in this paper contributes to the individual evaluation of control point relevancy in digital business ecosystems in general and support individually firms to examine its control point position in a digital business ecosystem.

To our best knowledge, this is the first paper providing a conceptual overview of different control points and how they dynamically evolve over time within the digital business ecosystem. Overall, our work contributes to strategy research in the field of (digital) business ecosystems by including the perspective of control points and deriving strategies how companies can set and shape control point constellations. Hannah and Eisenhardt (2018) suggest that business ecosystem strategies vary in a balance of cooperation and competition, and companies can follow different strategies within an ecosystem, i.e., system strategy, component or bottleneck strategy. In addition, our data reveals that ecosystem strategies highly depend on the level of control a single company has within the entire business ecosystem.

In the beginning, starting from an individual company perspective, companies need to decide how they may engage in the ecosystem. In line with Jacobides et al. (2019), we have observed that there are a few actors already possessing a strong position in the industry, who are able to build their own ecosystem. Other actors rather participate as complementors or strategic partner in different ecosystems, while seeking to strengthen their connection to complementary actors and to eventually move closer to the end customer.

Referring to our multiple-case study, we can, on the one hand, consider the digital agricultural industry as a business ecosystem as its own, as all actors involved in this ecosystem are somehow dependent on each other and strive for the overall common EVP of *'making farming more precise and sustainable'* (in line with Thomas & Ritala, 2021). However, on the other hand we can observe that different actors seek to establish a dominating position in the digital agricultural business ecosystem. For example, existing market leaders from the traditional agricultural machinery industry characterized by a large vertical integration try to build an own ecosystem providing a platform for selective partners offering digital services to the users within that ecosystem. Hence, these actors try to further leverage their market power. These actors still have a large share in providing the physical products and devices, e.g., tractors or other harvesting machineries, to the user. Although innovation increasingly emerges in information and digital technologies and less in machine engineering, machines are still necessary on the basic layer, as harvesting is and remains physical work which cannot be fully replaced by digital technologies (except from fully data-driven robotic systems in the future). However, the value in machines is increasingly driven by their software and additional digital functionalities. These functionalities rely on the analytics and digital service layer, where for example control points such as having the *data* or *customer access* leading to more customer insight or *know-how* being able to contribute (digital) content to the business ecosystem and its users can be added. Next to the large vertical integrated companies, technology providers try to address the current problem of missing compatibility between different actors (i.e., machinery, digital service provider or dealer) and build up a cross-industry infrastructure enabling *agility* and *salability* for all participants. Accordingly, they particularly contribute to the EVP by bridging the digital and physical world.

However, as we dealt with qualitative data only and an emerging business ecosystem, our research can only provide estimations on the impact of individual control points on the EVP and the percentage share of individual actors in value creation and value capture by means of different control points. We encourage subsequent quantitative research to follow up on our control point framework to deliver support for our assumptions by investigating real profits of individual actors or conducting a survey with companies letting them evaluate the relevancy of the respective control points and layers. Future research should also explore how individual control points influence each other. Control points are dynamically set and occupied by ecosystem actors during the evolution of digital business ecosystems. Future research may explore this evolutionary process in more detail and assess how companies may respond to changing situations in the emerging digital business ecosystem while occupying or setting new control points. In this regard, our suggestions are illustrated in the appendix in Figure A4. Further, our work suffers from the limitation that it is not based on longitudinal insights in the different actors' strategies. Although we were able to get insight into a variety of different actors' strategies, future research could expand the number of expert interviews per company. Also, subsequent research may incorporate the impact of digital technologies or the role of companies in digital business ecosystems in the context of sustainability (Bohnsack et al., 2022). Companies have the ability to create impact for social and environmental sustainability and thus set control points in requiring and achieving certain sustainability goals. Thus, additional value can be generated. Additionally, future research should incorporate the contractors' perspective, as they have an important role in the widespread adoption of precision farming (Wang, Huber, & Finger, 2022) and might have an influence on the competitive environment of the digital agricultural business ecosystem. Next, by including other data sources, such as business reports, research publications or results from strategy workshops, it is possible to gain a broader perspective on the companies' current and future potential bargaining positioning and to reduce general limitations of qualitative research.

5 Discussion and conclusion

This chapter summarizes the findings of the empirical studies presented in the previous chapters (section 5.1) and discusses the relationship between the three perspectives (1) technology, (2) company and (3) ecosystem (section 5.2). Moreover, it highlights the scientific and practical contributions of the thesis (section 5.3 and 5.4) as well as presents limitations and directions for further research (section 5.5) before concluding with some final remarks (section 5.6).

5.1 Summary

Grand societal challenges, such as climate change or environmental degradation, thus, sustainability transitions, cannot be solved by single organizations but require systemic changes, in which business, government and civil society play different roles (Loorbach et al., 2010; Talmar et al., 2020). Next to implementing the perspective of different actors, technological innovations play a central role in driving sustainability transitions (Geels, 2002; Hausknost et al., 2017; Laibach et al., 2019; Markard et al., 2012). In line with the theoretical perspective on emerging technologies (Day & Schoemaker, 2000; Rotolo et al., 2015) and the particularities of SOTs often being interdisciplinary (Borge et al., 2022; Borge & Bröring, 2017), potentially inducing systemic change (Geels & Schot, 2007) and being in strong competition with prevailing less sustainable technologies (Bohnsack et al., 2014; Bröring et al., 2020), their market implementation is fairly challenging. To achieve a systemic change towards a more sustainable economy, new potential technologies need to diffuse from scientific knowledge into marketable processes (Geels & Schot, 2007; Vandermeulen et al., 2012). In order to allow a transfer to commercial applications, scientific knowledge embedded in emerging technologies must be, first, identified as well as evaluated and second, perceived as economically viable. In this regard, business plays a crucial, but less explored, role within sustainability transitions and the commercialization of emerging SOTs.

Accordingly, this thesis has been motivated by the following two main research objectives:

I. To derive criteria for the evaluation of emerging SOTs from business perspective

II. To derive strategies how companies can position in an emerging business ecosystem driven by new technologies

To achieve these objectives, this dissertation conducted three empirical studies which aim to answer four research questions. In the following, the most relevant findings answering these research questions will be briefly summarized and discussed.

The first study (*chapter 2*) uses secondary data sources, namely patent and publication documents, to gain a comprehensive overview of emerging technologies. However, the bridging of both data sources with respect to a particular technology field is often challenging as for instance time lags between cross-citations complicate the evaluation of connectivity. Previous literature in the domain of technological forecasting, which has introduced approaches to bridge these data sources, is focusing most often on the actor level in terms of authors or assignees (van Looy et al., 2006), instead of operationalizing a technology-based approach. Thus, the first study aims at answering the first research question:

RQ1: How can sustainability-oriented technologies be identified and evaluated by means of secondary data sources?

Applied to the case of phosphorous recovery as an emerging SOT field, this study proposes a semantic similarity analysis approach of patent and publication documents extending the semantic patent analysis approach by Niemann et al. (2017). Therefore, by adopting a holistic perspective the study aims at simultaneously looking at knowledge from scientific publications (mirroring scientific research) and patents (reflecting technology fields) to understand the underlying dynamics of emerging technologies in a context of sustainability transitions. The approach relies on the total number of patents, the number of all similar publications, the number of single publications and the ratio of number of publications per patent for each patent lane to establish an indicator-based ranking of the technology clusters called patent lanes. Mapping the timely development of emerging sub-technologies in the domain of phosphorous recovery and the new developed indicator, the number of semantically similar publications per patent belonging to a specific sub-technology, contribute to the identification and evaluation of emerging technologies in the highly dynamic context of sustainability transitions.

To describe the content of the most frequented patent lanes, this study uses the top 10 bigrams according to the highest Tf idf values of a patent lane including text from title, abstract and claim. The external validation with a set of three experts reveals that depending on the perspective and level of prior knowledge in the respective technology field, the interpretation of the semantic patent and publication bridging approach varies. Furthermore, the external validation shows that relying on a single data source, such as patents only, is not reliable when evaluating an emerging technology. In the case of phosphorous recovery from wastewater, there are technology clusters that are highly prominent and promising technology clusters also when it comes to implementing phosphorous recovery technologies in pilot plants. However, in terms of patent documents there are other technology clusters being more frequented. Only by including the number of similar scientific publications the relevance of the technology field could be identified.

In order to further contribute to the first research goal, to derive criteria for the evaluation of emerging SOTs from business perspective, the integration of different stakeholders is necessary (Carraresi et al., 2018). Shared expectation can reduce the perceived uncertainty among technology developers and accordingly, guide the process of technological change (Alkemade & Suurs, 2012). This is also relevant for sustainability-transitions considering the multi-level and multi-actor perspective (Markard et al., 2012). Accordingly, the second study (*chapter 3*) aims at answering the second and third research question.

RQ 2: What are the criteria for selecting a sustainability-oriented technology from a value chain spanning perspective in the case of the bio-based economy?

RQ 3: How do the perceptions of relevancy of these criteria differ between stakeholders along value chains of the bio-based economy?

The results of the second study, the GCM study, reveal 59 selection criteria for SOTs being relevant for business stakeholders along the value chain of the bio-based economy. These criteria are sorted into 11 clusters, namely *value of sustainability*, *external communication and customer orientation*, *future competitiveness*, *economic viability*, *corporate entrepreneurship*, *technical feasibility*, *ease and controllability of technology integration*, *presence of needed capabilities*, *access to networks and open innovation*, *industry supporting conditions and compliance with political and legal frameworks*. These clusters are summarized into four dimensions. Accordingly, the implementation of SOTs involves (1) *market environment and viability*, (2) *corporate strategy and technology integration*, (3) *capabilities and knowledge exchange* and (4) *institutional and regulatory frames*.

By taking a value chain spanning perspective in assessing the relevancy of different selection criteria within the GCM study, this thesis provides answers to RQ3 and contributes to the understanding of coherence vs. non-coherence in technology evaluation across different value chain actors (i.e., agricultural and feedstock, (bio)-chemical and consumer industry). The data of the GCM study reveals that all stakeholders agree that on average the criteria of the clusters *external communication and customer orientation* as well as *future competitiveness* and, in particular, the criterion *economic profitability*, hence criteria of the market dimension, are highly relevant. Furthermore, the study shows that companies (or even industries) throughout the value chain rate short-term oriented technology selection criteria, for instance sorted to *technical feasibility* and *ease and controllability of technology integration* as comparatively high. The cluster *access to networks and open innovation* contains criteria which refer to long-term goals to be pursued in sustainability transition. Results show that these criteria have been, however, rated as comparatively low, especially by the agricultural and feedstock and consumer industries within the bio-based economy. Also, for the agricultural and feedstock industry *compliance with political and legal frameworks* and the *presence of needed competencies* are more relevant than for the other industries in the value chain. Moreover, results of the pattern match indicate that the (bio)-chemical industry seems to be readier for systemic changes than other actors in the value chain (Rigall & Wolters, 2019). In contrast, the consumer industry seems to be less willing to change existing systems, including value chains and infrastructures. The underlying selection criterion, *the technology's potential to cause a systemic change of value chains beyond the company's boundaries,* was one of the least coherently rated criteria among all stakeholder groups.

Following from the systemic character of many SOTs, not only value chains but entire ecosystems need to jointly create value to achieve sustainability transitions and an economic added value. For example, with the advent of digital technologies, also often considered as SOTs, incumbent companies with physical products shift from vertically organized value chains towards rather complex value networks in digital business ecosystems. Companies leave their original, well-understood bargaining position, where they are aware of who creates how much value and how much control they have in negotiating value capture, into a position in a digital business ecosystem, in which control over value creation is dispersed among multiple actors, across different industries and encompassing different layers (e.g., physical products, networks, digital services and content) within digital business models. Consequently, competitive advantages are redefined and tensions between value creation and value capture increases, as value creation occurs by means of cooperation but value capture is determined by a bargaining relationship. Accordingly, and in order to contribute to the second research goal, to derive strategies how companies can position in an emerging business ecosystem driven by new technologies, the third study answers the fourth research question:

RQ4: How do companies position themselves to achieve bargaining (market) power and a competitive advantage in an emerging digital business ecosystem?

While drawing upon information system literature, the third study investigated the concept of control points that constitute value capture mechanisms in the dynamic bargaining situation of emerging digital business ecosystems. By means of a multiple-case study with 15 companies, industry associations and consultancies in the digital agricultural ecosystem, the study identifies 13 different control points categorized into technical and strategic control points and two institutional boundary conditions emerging on the way from the traditional linear value chain towards digital business ecosystems. Subsequently, the study develops a control point portfolio, shows its evolution over time and changing EVP and derives control point strategies how companies enable value capture mechanisms and occupy control points in light of threats, such as technological or institutional change. Eventually, the study reveals three control point strategies to achieve bargaining (market) power, (1) the analog to digital, (2) the digital entrant and (3) the lateral entrant based upon an actor's individual strengths and original position and market focus. To be competitive in the long term, the expert interviews within the multiple-case study also reveal that it is essential to break silos as well as think and collaborate across industry boundaries.

5.2 General discussion

In the following, the relationship between the different studies within the scope of this dissertation will be discussed. Figure 5.1 visualizes the relationship between the three perspectives (1) technology, (2) company and (3) ecosystem and the major results of this dissertation. The perspectives can be sorted into a 'pre-commercialization' and a 'commercialization' phase indicated by the two grey shaded areas in Figure 5.1. Although the individual studies in this dissertation look at the emergence of SOTs from different perspectives, the business or organizational perspective plays the most important overarching role. The three studies have a similar starting point, namely the role of companies or industries in general in fostering the market implementation of emerging SOTs potentially leading to a transition towards a more sustainable economy. It should be noted that the boundaries between the different perspectives (1) technology, (2) company and (3) ecosystem are, however, blurring.

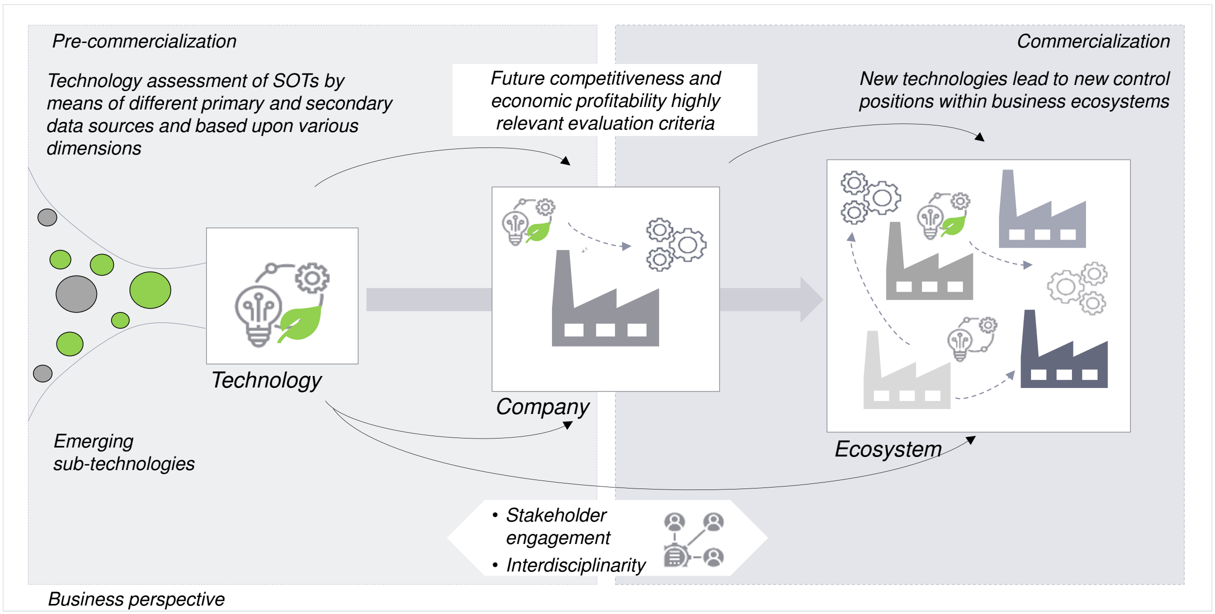

Figure 5.1: The relationship between the three perspectives, (1) technology, (2) company and (3) ecosystem, and the major results within the framework of the dissertation.

The first study clearly centers around a specific emerging technology, namely phosphorous recovery, and hence seeks to identify and evaluate an emerging technology itself, which has led to the focus on a technology perspective. However, as this study also considers scientific knowledge, it also integrates a science perspective for technology assessment. From the transition theory perspective, the first study particularly contributes to the micro-level of sustainability transitions (Geels, 2002) (see Figure 5.2). In addition, companies are an important addressee eventually applying the newly developed semantic patent and publication bridging approach for measuring emerging SOTs. This leads to an overlap with the second study, which emphasizes the company perspective. On the pre-commercialization side, insights derived from the first two studies reveal that the technology assessment of SOTs needs (1) different data sources, namely primary and secondary data, and (2) different dimensions.

The second study is interested in the company perspective on the evaluation of emerging SOTs. Results of this study build the bridge between pre-commercialization and commercialization, and hence deliver a major contribution to the overall goal of this dissertation to foster the transfer of emerging SOTs from science to industry. It reveals that future competitiveness and economic profitability are highly relevant evaluation criteria. However, since not only a single company perspective but rather various company and business perspectives aggregated on system perspective, i.e., value chain perspective, are considered, this paper also contributes to the ecosystem perspective accentuated in the third study of this thesis. The second study stresses that a coherent perception and understanding of technology evaluation across company boundaries are important to achieve a regime change, which means a diffusion of SOTs from micro- to meso-level (see Figure 5.2). However, the second study also highlights that SOTs are strongly competing with other, non-SOTs (see *future competitiveness* and *economic viability*). Accordingly, there is a competition between different niche innovations, which is also indicated in Figure 5.2, where black and green arrows, i.e., less sustainable and sustainable niche innovations emerge. For successful sustainability transitions, that could imply that collaboration or co-creation between SOTs and non-SOTs is also needed.

The third study has a wider scope and takes an ecosystem perspective. On the market side, in the phase of commercialization, a new SOT needs to connect and integrate with incumbent technology(-systems) and actors (i.e., companies) to form a new socio-technical regime based upon the multi-level perspective of transition theory, which is also reflected in Figure 5.2. Emerging technologies enable actors in business ecosystems to possess new control positions to exert influence on other actors in the ecosystem. More specifically, if an emerging SOT can outperform less sustainable technologies, it offers potential to occupy control points that enable value capture. Moreover, all three studies and perspectives as well as their individual results have in common that they point towards the interdisciplinarity of SOTs and that there is a need for stakeholder engagement to achieve sustainability transitions.

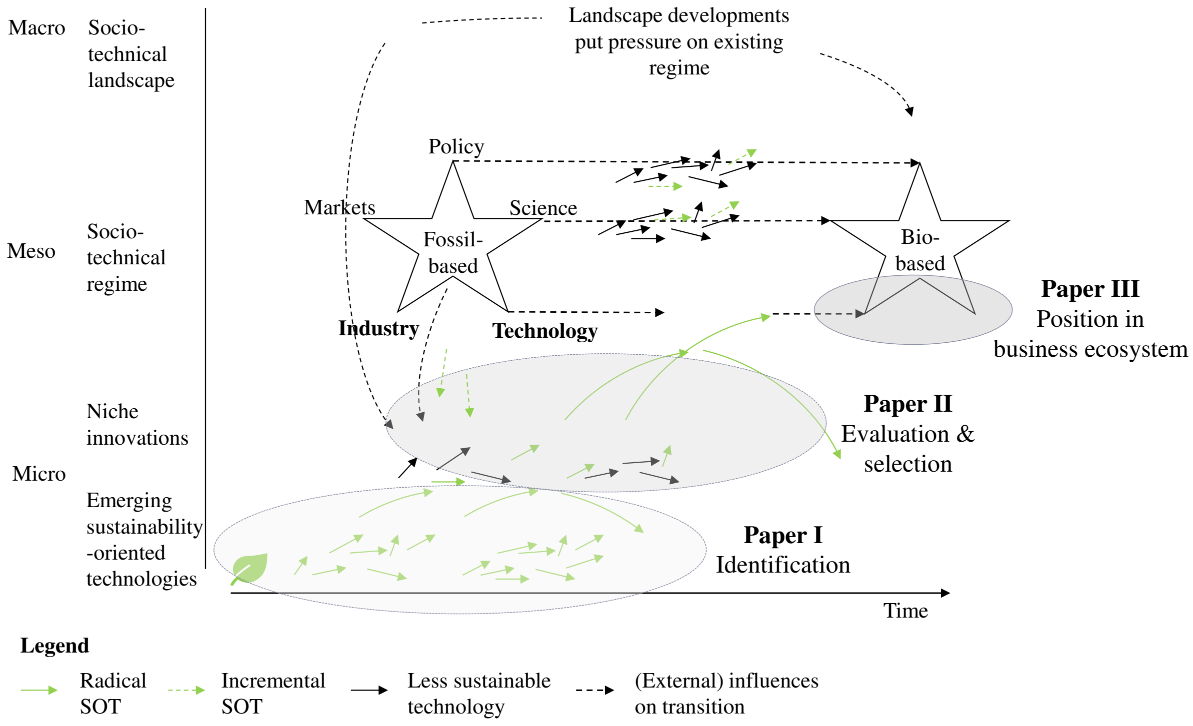

Figure 5.2: Three papers embedded in the multi-level perspective of transition theory.

5.3 Scientific contributions

Through the individual studies assessing emerging technologies from a technology, company and ecosystem perspective this thesis adds to extant literature in the domains of strategic (technology) management and sustainability transition research. The first study has stronger methodological implication, whereas the second and third have methodological and theoretical implications.

5.3.1 Theoretical implications

The concept of emerging technologies is the underlying theoretical background of this dissertation. From a technology perspective, this dissertation contributes to the understanding and forecasting of emerging technologies. Measuring the patent lane’s number of patent applications over a period of time shown in *chapter 2* contributes to the operationalization of growth and coherence that are attributes of emerging technologies (Rotolo et al., 2015). Also, the underlying semantic analysis adds to the classical citation analysis in terms of timely availability (Liu et al., 2010). Chapter 2, eventually, provides a new indicator to reflect the ratio of scientific (publication) vs. technological (patents) knowledge in a given domain. Adding publications to the technology cluster leads to different evaluations of emerging technologies compared to an assessment based on single data sources. Thus, the evaluation of the standard criteria characterizing an emerging technology based on single data sources might be highly limited. Eventually, insights from the first study contribute to Burmaoglu et al.'s (2019) understanding on technology emergence from complexity theory perspective that quantitative newness (e.g., measured by patent and publication data) should be also supported by expert judgments to convert these findings to qualitative newness (i.e., qualitatively different).

Sustainability transitions are long-term and multi-dimensional transformation processes (Markard et al., 2012), which are accompanied by incremental and radical technological innovations (Bröring et al., 2020; Szekely & Strebel, 2013). From company perspective, this dissertation, however, shows in *chapter 3* that companies (or even industries) throughout the value chain rate short-term oriented technology selection criteria sorted for instance among *technical feasibility* and *ease and controllability of technology integration* as comparatively high. *The access to networks and open innovation* could be, for instance, matched with the long-term goals to be pursued in sustainability transition. However, here the results within chapter 3 show that these criteria have been rated as comparatively low, especially by the agricultural and feedstock and consumer industries. Hence, for transition theory, that means actors along the value chain reveal varying readiness for long-term changes being necessary for sustainability transitions.

Insights of *chapter 4* in this dissertation primarily contribute to sustainability transition in the long run, as control points can be seen as a vehicle to derive new valuable business models. Business model innovation may be seen as a driver for system-wide sustainability transitions (Bolton & Hannon, 2016) and the link between technology and economic value creation (Björkdahl, 2009; Desyllas & Sako, 2013), which is ultimately important to foster the transfer of emerging SOTs from science to industry and achieve a sustainability transitions. Further, in the context of sustainability transitions, firms often seek to shape the institutional environment through lobbying or by strategically influencing collective expectations (Köhler et al., 2019). The influence of control points on institutional boundaries, such as *market design* or *state intervention* contribute to the understanding and operationalization of how companies can shape the institutional context.

Summarizing, on the one hand, this dissertation contributes to the long-term perspective of sustainability transitions including long-term transformation of socio-technical systems (e.g., from fossil-based to bio-based economy; transportation or electricity supply) towards sustainability (Smith, Voß, & Grin, 2010). Especially chapters 2 and 3 underline that it is indeed a socio-technical and not exclusively a technical transformation of the current regime, as stakeholders and the entire ecosystem must be taken into account in the transition (Geels, 2011; Kivimaa, Laakso, Lonkila, & Kaljonen, 2021; Markard et al., 2012).

On the other hand, this dissertation contributes to the short-term and firm-level perspective how companies may create value while exploring companies' perceptions towards relevant selection criteria for SOTs in chapter 3 and the role of control points in gaining competitive advantages from an ecosystem perspective in chapter 4. The short-term perspective adds to research on the role of business models for sustainability while analyzing how companies may create value by sustainable business models (Aagaard et al., 2021; Bähr & Fliaster, 2022; Boons & Lüdeke-Freund, 2013).

Furthermore, this thesis contributes to strategy research in the field of (digital) business ecosystems by including the perspective of control points and deriving strategies how companies can set and shape control point constellations (e.g., Bohnsack et al., 2021; Hanelt et al., 2020). Hannah and Eisenhardt (2018) suggest that business ecosystem strategies vary in a balance of cooperation and competition, and companies can follow different strategies within an ecosystem, i.e., system strategy, component or bottleneck strategy. In addition, results of chapter 4 reveal that ecosystem strategies highly depend on the level of control a single company has within the entire business ecosystem. In contrast to Hannah and Eisenhardt's (2018) results, all control point strategies developed in chapter 4 within this dissertation, depend to a certain degree of cooperation (i.e., networking).

Prevailing theories and concepts, such as the IO perspective being dominated by Porter's 5 forces framework (Porter, 1980), the value chain concept (Peppard & Rylander, 2006) or the RBT (Barney, 1991; Wernerfelt, 1984) provide an insufficient explanation of how companies manage to achieve a competitive advantage in a digital business ecosystem. This dissertation, elaborating on the concept of control points, eventually, contributes to the more recent value network lens (Peppard & Rylander, 2006) which helps to broadly understand co-creation of value, but does not yet offer any insights on how that jointly created value can be captured by individual actors.

5.3.2 Methodological contributions

This thesis has methodological contributions within each chapter, of which in particular the new developed patent and publication bridging approach in *chapter 2* is worth to be highlighted. The approach developed in chapter 2 contributes to technology forecasting. The study extends the patent based similarity analysis by Niemann et al. (2017) while applying it on the dynamic field of SOTs and additionally combining it with publication data. Thus, the evaluation of emerging technologies can be built upon a broader range of information and likewise enables to integrate an ever-increasing amount of textual data. This can lead to higher construct validity compared to an assessment on single data sources and thus may allow us to get a better understanding of technology (Eisenhardt, 1989; Yin, 2003). Here, construct validity refers to the establishment of correct operational measures for the concepts being studied (i.e., emerging technologies) (Yin, 2003). Eventually, the study establishes a new indicator-based ranking of the technology clusters, i.e., patent lanes.

Whereas previous literature primarily integrated both, patent and publications data, through parallel analysis (Goeldner et al., 2015; Naumanen et al., 2019), or bibliometric approaches, such as co-authorship or co-citation of patent and publications often suffering from time lags (Narin et al., 1997; Tussen et al., 2000), the semantic similarity analysis provides a direct technology linkage (Wustmans et al., 2021). Additionally, most research on the assessment of emerging SOTs from a technology perspective is dominated by applying environmental accounting tools, such as LCAs or carbon foot printing (Arvidsson et al., 2018; Bergerson et al., 2020; Patterson, McDonald, & Hardy, 2017). Accordingly, this thesis contributes to the methodological approaches for assessing emerging SOTs for strategic technology management (e.g., Nordensvard et al., 2018; Park, Lee, & Jun, 2015).

Moreover, in chapter 2, this thesis shows that an assessment of emerging technologies based on only one data source may lead to wrong conclusions, which leads to the need for different data sources in combination with expert opinions to make sense out of emerging phenomena, such as phosphorous recovery technologies as an emerging SOT. Thus, this thesis uses secondary and primary data and applies qualitative and quantitative approaches to assess technologies from different perspectives (Burmaoglu et al., 2019).

In *chapter 3*, technology selection criteria for SOTs have been derived. These criteria can be added to prevailing technology assessment tools (e.g., Cartalos et al., 2018; Heslop et al., 2001) and hence, provide methodological implications for technology assessment in general. Further, as an extension of the conventional GCM process (Kane & Trochim, 2007), the study within chapter 3 applied the generated results, i.e., selection criteria for SOTs, within a workshop with researchers in order to evaluate a specific SOT in the context of a research project on plant protection, showing the practical applicability of the selection criteria and, in general, the results of a GCM study.

In addition, the control point framework developed in *chapter 4* can be considered as a method of analysis contributing to the understanding of relationship between different actors, their roles and functions in the business ecosystem (Dedehayir et al., 2018). Eventually, the manifestation of control points might help in deriving new or adapted digital business models at the interface between physical and digital layers (Eaton et al., 2010). Furthermore, it is the first time, that the modular layered architecture drawn from information system literature (Yoo et al., 2010) has been combined with the ecosystem pie model by Talmar et al. (2020) to investigate value creation and value capture mechanisms leading to new insight how different actors contribute to the EVP across the modular layered architecture.

5.4 Practical contributions

Several practical contributions can be derived from the research results of this dissertation. There are manifold managerial implications, as this thesis takes a business view and seeks to contribute to the transition of current business towards greater sustainability. Further, there are also political implications which can be derived from the three studies.

5.4.1 Managerial contributions

From a business perspective, technology dynamics and the change involved with the sustainability transition present not only challenges for the current business but also offer huge potential for innovations and new business opportunities (Hansen et al., 2009). Accordingly, this thesis has aimed at fostering the implementation of emerging SOTs in industry while particularly addressing the role of incumbents. Together, the three studies within this dissertation have three main managerial contributions, namely to support (1) the decision-making process of managers when assessing and selecting emerging SOTs, (2) the subsequent innovation process including different stakeholders, and (3) the examinations of firm's individual control point position in an emerging business ecosystem.

First, the semantic bridging approach of patent and publication data elaborated in chapter 2 provides a technological forecasting tool, which helps managers gaining a first overview of the research and technology landscape in a certain field and to identify appropriate technologies as well as, if including patent assignees, potential collaboration partners for future projects. Also, it helps in detecting a company's position within a technological field in comparison to its competitors. Depending on the prior knowledge of the manager the subsequent evaluation of the results has to be done in collaboration with researchers or engineers in the field (Reger, 2001). Thus, in order to guarantee sense making of the approach, interdisciplinarity plays an important role in the evaluation of emerging SOTs. Eventually, the depiction of the development of different emerging technologies by means of patent lanes and the bridging of publication data serves as a criterion for managers while deciding upon investing in a particular emerging SOT. Additionally, the technology selection criteria derived in chapter 3 can be applied by managers on a concrete SOT to evaluate its appropriateness for the individual company.

Second, for the subsequent innovation process of emerging SOTs, this dissertation provides insight into the perception of different stakeholders (e.g., managers) across the value chain towards their priorities in evaluating SOTs. Results of chapter 3 contribute to the understanding that *external communication and customer orientation* are highly relevant technology selection criteria for all stakeholders. That means, the entire customer experience could be incorporated by, e.g., including the customer already when developing new SOTs to not overstrain the customer after commercialization, highlighting that user involvement also plays a central role in sustainability transition (Markard et al., 2012; Moretti, Baum, Wustmans, & Bröring, 2022). Depending on the corporate strategy, different criteria might be more relevant. For instance, companies with a short-term focus prefer incremental innovations over radical ones, as they are more predictable (Montgomery, 2017). Accordingly, criteria related to *economic viability* or *technical feasibility* are more relevant for this kind of companies. Companies are advised to recognize the distinctive industry characteristics and work on solutions that address bottlenecks, preferably in a co-creative manner with the implementing firm to enable a co-development and therewith the alignment of potential interfaces. It has been shown that the involvement of the implementing firm in the innovation process leads to an increase in problem ownership of the sustainability impact and acceptance of the technology, than if it had been developed in isolation (Lang et al., 2012). Besides active engagement in open innovation approaches with innovating firms and participation in industry networks, the implementing firm should enable organizational structures that allow cross-functional and cross-organizational collaboration (Chesbrough, 2006). Hence, it may increase absorptive capacity and bridge internal knowledge gaps, thus build the necessary assessment and implementation capacity for SOTs (Messeni Petruzzelli et al., 2011; Zahra & George, 2002). Firms are also encouraged not to evaluate SOTs for their seamless substitution potential, as they are unlikely to be able to compete with the existing technology base used in the firm. Instead of considering the sustainability aspect of a technology as an additional attribute in their evaluation, managers should develop strategies to capitalize on this sustainability aspect. The increased importance investors attach to sustainability rankings will ensure long-term profitability and competitive advantage by pursuing a holistic sustainability strategy that puts SOTs at the center of their activities.

Third, for companies sustainability transitions also mean the necessity to move to new or more sustainable VPs (Schaltegger, Hansen, & Lüdeke-Freund, 2016). These business models must not only provide economic value for the company, but also across organizational borders, to its stakeholders, the society and environment (Bähr & Fliaster, 2022). Results of chapter 4 show for instance that within digital business ecosystems driven by emerging SOTs, such as smart and precision farming technologies, the competitive advantage does not solely rely in the company's own resources, but rather in the company's ability to connect to other actors and to complement own resources, while eventually contributing to the EVP. Managers should be also aware that actors outside their original industry strive to enter the emerging business ecosystem. To achieve an EVP, it is important that companies do not consider them as rivals but as potential collaboration partners and co-creators. As it is challenging to coordinate (interfirm) *modularity* that may increase interdependencies between ecosystem actors, companies are advised to manage interdependencies (Staudenmayer et al., 2005) through for instance fostering common standards or lobbying towards a desired *market design*.

The framework of control point (portfolios) that are firm-created positions in a digital business ecosystem which determine the possibility to capture value (today and in the future) developed in this dissertation contributes to the evaluation of control point relevancy in emerging business ecosystems in general and support individually firms to examine its control point position in an emerging business ecosystem. Within the modular layered architecture (Yoo et al., 2010), with an increasing amount of data and an increasing relevance of cloud computing, IoT and institutional changes, control points in the digital world as well as control points on the connectivity layer gain even more relevancy. That means, to remain competitive in the digital world and an emerging business ecosystem driven by digital technologies, companies are advised to acquire control points on digital layers, i.e., analytics and digital service, as they contain a larger potential to contribute to the EVP and thus, for companies to create and capture value in the end.

5.4.2 Policy implications

Technology emergence attracts policy makers' attention, as they lead to changes in current capabilities and a need for early warning indicators (Burmaoglu et al., 2019). The identification of relevant emerging technologies is not only pivotal for innovation managers and researchers, but also policy makers, as they need to anticipate the future development and impact of emerging technologies, too, in order to set strategic priorities (Rotolo et al., 2015). International policies can shape technological trajectories (Bohnsack, Kolk, & Pinkse, 2015). Especially, for technologies which are still emerging and cannot ultimately compete with incumbent technologies, such as SOTs, a clear and consistent government policy is highly important (Negro, Suurs, & Hekkert, 2008).

Accordingly, as already elaborated in the methodological contribution (section 5.3.2), the in chapter 2 newly developed semantic bridging approach can be also used by policy makers to identify and evaluate technology emergence. In collaboration with experts in the respective technological field, policy makers can benefit from this approach by gaining a holistic overview of an emerging technological field. Furthermore, results of the GCM study in chapter 3 confirm that stakeholders expect regulatory certainty and planning security. Especially, the economic viability of the technology, independent of subsidies and, in the event of changing regulations, the threat of sanctions, are important aspects to be considered regarding the regulatory framework of a SOT. Due to the positive social and environmental impacts of SOTs, policymakers have an interest in their broad market implementation and therefore adopt laws and regulations that promote their broad transfer and diffusion. However, regulations only reflect the current knowledge base about the sustainability impacts of SOTs and need to be adjusted if unexpected implications and emerging social injustices arise from the implementation of certain solutions that were once promoted by regulation, such as for example the debate on bioenergy vs. world food. If existing regulations need to be amended, this should be done in a predictable and credible manner. For the adoption of new regulations, regulations should be evidence-based and provide an appropriate transition period (Mickwitz et al., 2008).

Additionally, the results of the GCM study in chapter 3 provide a comprehensive visualization of relevant selection criteria for SOTs in form of a concept map, a cluster rating map as well as a pattern match across different stakeholder types. These maps can be used as a guidance for targeted – stakeholder specific – action planning and the evaluation of research projects to assess their future financial supportability. For example, this dissertation shows that the agricultural and feedstock industries within the bio-based economy are particularly attentive to existing regulations and compliance with them and consider them highly relevant when selecting SOTs.

Chapter 4 shows the relevance of institutional boundaries, i.e., *market design* and *state intervention*, for creating an EVP in a nascent business ecosystem around emerging SOTs, such as digital technologies in the agricultural ecosystem. Insights of this study indicate that institutional boundaries have an influence on companies' technical control points since they set the external boundaries and moderate the value creation and capture potential. It should be noted that in the digital agricultural ecosystem, public authorities may become even more relevant in the future, as they might be responsible for harmonized data structures and digital infrastructures as well as providing certain data and services for free. In this way, policy can help promote the use of digital and precise technologies in agriculture. Institutional boundaries can be also considered as triggers leading to dynamic changes of business models, i.e., towards setting particular control points (Trossen, 2005).

Summarizing, these policy implications have an influence on sustainability transitions. Insights generated in this dissertation confirm that the interaction of companies, i.e., industry with policymakers is important to achieve long-term sustainability transitions. The role of policy is to manage a wider system transformation while monitoring progress in rapidly diffusing innovations and supporting complementary innovations such as infrastructure to avoid critical bottlenecks (Markard, Geels, & Raven, 2020).

5.5 Limitations and directions for further research

This dissertation stresses the role of technology and companies in fostering sustainability transitions. It has particularly addressed three challenges for business associated with assessing emerging SOTs and their transfer from science to industry, namely high unfamiliarity of incumbents, high uncertainty and the systemic complexity of SOTs. Findings of the three studies within this dissertation deliver valuable scientific and practical contributions. However, this dissertation also has some methodological and theoretical limitations.

First, companies and technologies alone cannot achieve sustainability transitions. They involve structural and co-evolutionary changes in which institutional, technological, behavioral, ecological, economic and other processes intertwine and reinforce each other (Berggren et al., 2015; Loorbach et al., 2010). From transition theory perspective, it has to be mentioned that besides technological innovations leading to changes on the micro level, changes of the socio-technical regime (incl. e.g., industry, science and markets) as well as the overarching socio-technical landscape level need to interact to ultimately cause a transition (Vandermeulen et al., 2012). Hence, future research might use the results of this dissertation, such as the semantic bridging approach of patent and publication data to identify and evaluate an emerging SOT or different sub-technologies and match them with existing regulations, for instance in order to identify supporting or hindering regulations and thus, to also reflect on the socio-technical landscape level of the multi-level perspective of transition theory (see Figure 5.2). Further, future research might extend the ecosystem perspective and include more institutional actors (e.g., policy makers) as well as users/consumers to better reflect the market perspective. For example, subsequent GCM studies or expert interviews could include these actor types.

Second, the secondary data used in chapter 2 is limited in terms of deriving statements about real market implementation of the technologies. It may further be interesting to combine other data sources than patent and publication data to obtain more strategic insight into the evolving technology clusters and the real market. Parraguez et al. (2020) for instance used industry databases of R&D pilots and facilities and descriptions of research and innovation projects (e.g. R&D projects funded by the European Commission), which were bridged with publication and patent data by means of text mining analysis. Also, trend data can be bridged with patent data to evaluate innovation fields, i.e., emerging technologies (Wustmans et al., 2021). Moreover, Hain et al. (2020) for instance introduced an integrated market-technology perspective in the wind and electric vehicle sector, which incorporates different key market development indicators, such as installed capacity of wind energy or the stock of electric vehicle, which can be compared to the technology development by means of patents in the field. However, in the case of phosphorous recovery the integration of the market perspective still remains challenging, as we are still at the very beginning of implementing phosphorus recovery at a commercial scale. With respect to Shibata et al.'s (2010) approach to identify scientific research clusters, where no patent cluster corresponds to, the order of the approach within this dissertation might be reversed. That means instead of starting with the definition of technology clusters derived from patent documents, the semantic similarity analysis could first identify research clusters based upon publication documents and match patents to these clusters afterwards.

Accordingly, the seed for further innovation might be identified more easily (Shibata et al., 2010). Also, subsequent research could expand the methodological framework of chapter 2 by another step, which solely analyzes the semantic structure of patent documents, which are responsible for the opening of a new patent lane encompassing a single document only to gain a better understanding of its uniqueness. Additionally, the inclusion of IPC or CPC groups might be possible, in order to validate the accuracy of the semantic clustering approach. Although the results of chapter 2 were discussed with a few experts possessing the technological knowledge, identified technology clusters should be further validated by systematic, interactive forecasting methods, such as the structured Delphi method or a scenario technique.

Third, this dissertation has focused on SOTs in general, with a major focus on SOTs which result from radical innovations. However, future research may dive deeper into analyzing different types of emerging SOTs, such as generic technologies with a wide application spectrum (i.e., general purpose technologies such as electric motors) or proprietary technologies with a discrete application spectrum (e.g., “own” electric powertrain) (Haessler, Giones, & Brem, 2022). As results by Haessler et al. (2022) indicate, technology evaluation and characteristics with respect to a successful commercialization might differ between these types of emerging technologies.

Fourth, this thesis focused on the role of emerging technologies particularly introduced into the market as niche innovations. However, this dissertation has not critically differentiated between the role of newcomers vs. incumbents in driving sustainability transitions (Bohnsack et al., 2020). It could be explored which actors, i.e., incumbent regime actors or new emerging actors drive radical innovations at the niche level (Berggren et al., 2015) to enable even more specific recommendations how to foster sustainability transitions such as the transition from the fossil-based towards a bio-based economy. It might be also interesting to explore how new entrants’ and incumbents’ perception towards the evaluation and selection of emerging SOTs differ by for instance including a larger sample of start-ups vs. incumbents in future GCM studies.

Fifth, in line with the concept of microfoundation, this dissertation has explored individual perceptions towards technology evaluation within the GCM study in chapter 3 (Barney & Felin, 2013). Molina-Azorín (2014) claims that strategy research is usually located on the macro level to explain firm performance heterogeneity. However, in times of rapidly changing contingencies the processes of integrating and sharing knowledge are essentially dependent on efforts and skills of individuals on the micro-level, which cannot be assessed by comparing firm output data (Foss, 2010). This is the backbone of the concept of microfoundations which builds on the assumption that individual-level factors or rather the interaction of individual actors impact or mediate the organizational outcome on the macro-level (Barney & Felin, 2013; Felin, Foss, & Ployhart, 2015). Microfoundation research seeks to analyze the role of individuals and their motivation, cognitive processes and conceptual thinking of problems in order to better understand how aggregated perceptions and actions within an organization may emerge (Barney & Felin, 2013; Foss, 2010). However, in the GCM study within this dissertation only one individual per company was included within this study, which has led to the aggregated company perspective. This can be considered as a limitation of this dissertation. Additionally, there might be a gap between what stakeholders are claiming as relevant selection criteria and how they evaluate SOTs in reality. Accordingly, future studies might include more individuals from each company and in order to circumvent the general limitation of GCM studies, experiments such as discrete choice experiments (Wensing et al., 2020) or case studies might be conducted (Lee & Kim, 2011; Stalmokaitė et al., 2022).

Sixth, this thesis has focused on the role of SOTs in sustainability transitions. The focus of chapter 4 was the emergence of digital technologies. The thesis has elaborated the connection between digital technologies and SOTs and their overlap in fostering sustainability transitions. However, chapter 4 has not specifically included the aspect of sustainability within the control point framework (Bohnsack et al., 2022). Companies have the ability to create impact for social and environmental sustainability and thus set control points in requiring and achieving certain sustainability goals. Accordingly, future research may build upon the control point framework developed within this dissertation and analyze how and which control points can exert impact on actors' and EVP's sustainability. For instance, actors who possess the strategic control point *orchestration* might have a larger impact on the overall sustainability of the EVP. Also, future research might explore how control points can be allocated to the multi-level perspective of transition theory (Geels, 2002). For example, are control points more likely to be set by players from the existing regime (i.e. traditional agribusiness) or new players? In chapter 4 and especially Figure 4.7, this thesis already shows that there are different strategies based upon different going-in positions into the emerging digital agricultural business ecosystem. Here, for example, the 'digital entrants' can be described as niche players and the 'analog to digital' players as regime actors. From transition theory perspective, future studies might build upon these ideas to gain more insight into the drivers or inhibitors of the regime shift from traditional to digital farming.

Eventually, the creation of appropriate business models in the context of SOT commercialization is a challenge which is only partially addressed in this dissertation (Bohnsack et al., 2014). The business model perspective would subsequently follow as an outcome of this dissertation. The technical and strategic control points could be for example matched to the business model canvas (Osterwalder & Pigneur, 2010). Future research might explore or develop different types of business models based upon the control point logic developed in this dissertation. That might have implication for a more sustainable future, as business models offer the potential for system-wide sustainability transitions (Bolton & Hannon, 2016; Massa, Tucci, & Afuah, 2017). Also, in order to validate the control point framework developed in this dissertation, future research should discuss it with experts in the field of digital agriculture as well as apply it in other contexts, such as the connected car industry or the telecommunication industry (Bohnsack et al., 2021; Eaton et al., 2010).

5.6 Conclusion

In the framework of this dissertation, three empirical studies are conducted to assess emerging technologies from (1) technology, (2) company and (3) ecosystem perspective to foster the technology transfer of emerging SOTs from science to industry on the way towards a sustainability transition of current businesses. Findings reveal that there is a need for different primary and secondary data sources as well as various dimensions to assess emerging SOTs. Relevant dimensions for business in the context of sustainability transition include for example the market environment and viability or corporate strategy and technology integration. In order to achieve a sustainability transition driven by emerging technologies, actors need to jointly create value within emerging business ecosystems. Comprehensively, this thesis (1) advances methodologies within strategic technology management to assess emerging SOTs, (2) provides a conceptual framework for relevant selection criteria of SOTs from a value chain spanning perspective, and (3) develops a framework for companies to assess its competitive position within an emerging business ecosystem. For policy, this thesis highlights that regulatory certainty and planning security regarding the economic viability of the technology, independent of subsidies and, in the event of changing regulations are important aspects to be considered regarding the regulatory framework of SOTs. To avoid bottlenecks during the sustainability transition, policy should promote the complementarity and interoperability of emerging technologies. In addition, results allow for stakeholder targeted support initiatives to facilitate the technology transfer in the context of sustainability transitions.

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Appendix

Table A 1: Literature review on evaluation of emerging technologies in the context of sustainability.

Research approach	Example	Sum
Literature review	Marathe et al. (2021)	13
Life cycle assessment	Tsalidis and Korevaar (2022)	9
Methods for strategic technology management	Nordensvard et al. (2018)	6
Environmental assessment	Gao et al. (2020)	5
Societal impact assessment	Schaeffer et al. (2013)	3
Business model perspective	Reinhardt et al. (2019)	2
Assessing barriers in uptake of emerging technologies	Farhangi et al. (2020)	1
Assessing individual motives and visions and external boundary conditions	Krätzig et al. (2019)	1
Assessing role of incumbent intermediaries	Sovacool, Turnheim, Martiskainen, Brown, and Kivimaa (2020)	1
Assessing role of inter-organizational digital knowledge networks	Csedő et al. (2021)	1
Assessing role of policy	Hung and Chu (2006)	1
Assessing technology adoption	Niaki, Torabi, and Nonino (2019)	1
Assessing willingness to pay for emerging technologies	Zhang et al. (2020)	1
Determining commercialization strategies	Walsh (2012)	1
Developing a decision-making model	Lizarralde et al. (2020)	1
Environmental and socio-economic assessment	Bierbaum, Leonard, Rejeski, Whaley, Barra, and Libre (2020)	1
Fuzzy-analytic network process	Yadav and Singh (2021)	1
Measure acceptability	Ryan et al. (2020)	1
Opportunity and risk assessment	Rogers and Srivastava (2021)	1
Politics and economics assessment	Rotz et al. (2019)	1
Scenario development for decision support for emerging technologies	Malsch, Mullins, Semenzin, Zabeo, Hristozov, and Marcomini (2018)	1
Technology transfer assessment of corporates	Kolk (2015)	1
TIS approach	Andersson et al. (2018)	1
Sum		**55**

Table A 2: All papers within the literature review.

Nr.	Publication title	Source
1	Risk preventative innovation strategies for emerging technologies the cases of nano-textiles and smart textiles	Köhler and Som (2014)
2	Shaping factors in the emergence of technological innovations: The case of tidal kite technology	Andersson et al. (2018)
3	Emerging Sustainable Supply Chain Models for 3D Food Printing	Rogers and Srivastava (2021)
4	The Politics of Digital Agricultural Technologies: A Preliminary Review	Rotz et al. (2019)
5	The role of international business in clean technology transfer and development	Kolk (2015)

6	Prospective Environmental Analyses of Emerging Technology: A Critique, a Proposed Methodology, and a Case Study on Incremental Sheet Forming	Cooper and Gutowski (2020)
7	Technological competitiveness and emerging technologies in industry 4.0 and industry 5.0	Alvarez-Aros and Bernal-Torres (2021)
8	Towards sustainable business models for electric vehicle battery second use: A critical review	Reinhardt et al. (2019)
9	High-Tech Urban Agriculture in Amsterdam: An Actor Network Analysis	Farhangi et al. (2020)
10	Guides or gatekeepers? Incumbent-oriented transition intermediaries in a low-carbon era	Sovacool et al. (2020)
11	Innovation core, innovation semi-periphery and technology transfer: The case of wind energy patents	Nordensvard et al. (2018)
12	Assessment and Selection of Technologies for the Sustainable Development of an R&D Center	Lizarralde et al. (2020)
13	Innovation Nirvana or Innovation Wasteland? Identifying commercialization strategies for small and medium renewable energy enterprises	Walsh (2012)
14	Anticipating governance challenges in synthetic biology: Insights from biosynthetic menthol	Ribeiro and Shapira (2019)
15	Business models in emerging industries: some lessons from the 'Better Place' electric-car debacle	Olleros (2017)
16	Multi-level perspective to facilitate sustainable transitions - a pathway for German OEMs towards electric vehicles	Krätzig et al. (2019)
17	Spatiotemporal patterns of lithium mining and environmental degradation in the Atacama Salt Flat, Chile	Liu et al. (2019)
18	Green principles for responsible battery management in mobile applications	Arbabzadeh, Lewis, and Keoleian (2019)
19	Hydrogen Economy Development Opportunities by Inter-Organizational Digital Knowledge Networks	Csedő et al. (2021)
20	Stimulating new industries from emerging technologies: challenges for the public sector	Hung and Chu (2006)
21	An integrated fuzzy-ANP and fuzzy-ISM approach using blockchain for sustainable supply chain	Yadav and Singh (2021)
22	Novel entities and technologies: Environmental benefits and risks	Bierbaum et al. (2020)
23	Why manufacturers adopt additive manufacturing technologies: The role of sustainability	Niaki et al. (2019)
24	Environmental assessments of scales: The effect of ex-ante and ex-post data on life cycle assessment of wood torrefaction	Tsalidis and Korevaar (2022)
25	Uncovering the true cost of hydrogen production routes using life cycle monetisation	Al-Qahtani, Parkinson, Hellgardt, Shah, and Guillen-Gosalbez (2021)
26	Upscaling methods used in ex ante life cycle assessment of emerging technologies: a review	Tsoy et al. (2020)
27	Life cycle assessment of emerging technologies on value recovery from hard disk drives	Jin et al. (2020)
28	Environmental analysis of selective laser melting in the manufacturing of aeronautical turbine blades	Torres-Carrillo, Siller, Vila, López, and Rodríguez (2020)
29	How to Conduct Prospective Life Cycle Assessment for Emerging Technologies? A Systematic Review and Methodological Guidance	Thonemann, Schulte, and Maga (2020)

30	Life cycle considerations of nano-enabled agrochemicals: are today's tools up to the task?	Pourzahedi et al. (2018)
31	Current available treatment technologies for saline wastewater and land-based treatment as an emerging environment-friendly technology: A review	Marathe et al. (2021)
32	IoT-Based Smart Healthcare System: A Review on Constituent Technologies	Sahu, Atulkar, and Ahirwal (2021)
33	A holistic review of research on carbon emissions of green building construction industry	Lu et al. (2020)
34	Pharma Industry 4.0: Literature review and research opportunities in sustainable pharmaceutical supply chains	Ding (2018)
35	Additive manufacturing management: a review and future research agenda	Khorram Niaki and Nonino (2017)
36	Developing a sustainable energy strategy for a water utility. Part II: a review of potential technologies and approaches	Zakkour, Gaterell, Griffin, Gochin, and Lester (2002)
37	Smart recovery decision-making for end-of-life products in the context of ubiquitous information and computational intelligence	Meng, Cao, Peng, Prybutok, and Youcef-Toumi (2020)
38	Enhancing Sustainability and Energy Efficiency in Smart Factories: A Review	Meng, Yang, Chung, Lee, and Shao (2018)
39	Smart remanufacturing: a review and research framework	Kerin and Pham (2020)
40	What are Important Technologies for Sustainable Development in the Trucking Industries of Emerging Markets? Differences between Organizational and Individual Buyers	Zhang et al. (2020)
41	Marine Biotechnology: Challenges and Development Market Trends for the Enhancement of Biotic Resources in Industrial Pharmaceutical and Food Applications. A Statistical Analysis of Scientific Literature and Business Models	Daniotti and Re (2021)
42	Digitalization of construction supply chain and procurement in the built environment: Emerging technologies and opportunities for sustainable processes	Yevu et al. (2021)
43	Can Carbon Nanomaterials Improve CZTS Photovoltaic Devices? Evaluation of Performance and Impacts Using Integrated Life-Cycle Assessment and Decision Analysis	Scott, Cullen, Fox-Lent, and Linkov (2016)
44	A Network Analysis Model for Selecting Sustainable Technology	Park et al. (2015)
45	Semantic bridging of patents and scientific publications - The case of an emerging sustainability-oriented technology	Block et al. (2021)
46	Obtaining a Sustainable Competitive Advantage from Patent Information: A Patent Analysis of the Graphene Industry	Yang, Yu, and Liu (2018)
47	Barriers to adopting satellite remote sensing for water quality management	Schaeffer et al. (2013)
48	Technologies-based potential analysis on saving energy and water of China's iron and steel industry	Gao et al. (2020)
49	Decision Support for International Agreements Regulating Nanomaterials	Malsch et al. (2018)
50	Evolution of collaborative networks of solar energy applied technologies	Paulo and Porto (2018)
51	Developing stakeholder archetypes for enhanced landfill mining	Einhäupl, van Acker, Svensson, and van Passel (2019)
52	A Predictive Model of Technology Transfer Using Patent Analysis	Choi et al. (2015)
53	Implementation of technologies in the construction industry: a systematic review	Chen et al. (2022)

54	Environmental Impact and Levelised Cost of Energy Analysis of Solar Photovoltaic Systems in Selected Asia Pacific Region: A Cradle-to-Grave Approach	Ahmad Ludin et al. (2021)
55	The Ethical Balance of Using Smart Information Systems for Promoting the United Nations' Sustainable Development Goals	Ryan et al. (2020)

Table A 3: Demographic questions being asked in the sorting and rating process.

Nr.	Type	Question	Answers in the software
1	Stakeholder type	To which stakeholder type would you most likely classify yourself? Please base your answer on the main activity of your company.	1. Agricultural raw material 2. Chemistry / biotechnology (mainly B2B) 3. Food industry (mainly B2B) 4. Consumer goods (e.g., personal care, food, cosmetics, textile) 5. Consulting / industry network
2	Company size	How many employees does your company have?	• ≤ 9 employees • 10 - 49 employees • 50 - 499 employees • ≥ 500 employees
3	Understanding of sustainability-oriented technologies	Which sustainable technologies / innovations are the focus of your company or consultancy?	• Autonomous and incremental innovations (e.g., increasing eco-efficiency in existing processes in one's own company) • Autonomous and radical innovations (e.g., replacement of critical components by sustainable solutions within own company boundaries to arrive at a new more sustainable product) • Systemic and radical innovations (e.g., use of entirely new raw materials and processes that require a change in value chains and systems) • Systemic and incremental innovations (e.g., increasing eco-efficiency by implementing new efficient systems beyond the company's own boundaries)
4	Prior knowledge of sustainability-oriented technologies	How familiar are you personally with sustainability-oriented technologies or innovations?	• not at all familiar • a little familiar • moderately familiar • very familiar • extremely familiar
5	Sustainability orientation of the company	How long have environmental concerns been part of your innovation processes?	• not yet • do not know • since foundation of the company • ca. since ≤ 1 year • ca. since 1 ≤ years • ca. since 5 ≤ 10 years • ca. since 10 ≤ 20 years • ca. since 20 ≤ 30 years • ca. since ≥ 30 years

Table A 4: Sample description of stakeholders who participated in the rating process (1/3).

Stakeholder type and company size	**Time since environmental concerns have been part of company's / stakeholder's innovation processes**				
	not yet	≤ 10 years	≥ 10 years	since founding day	NA	Sum
Agricultural and feed-stock industry	**1**	**6**	**6**	**1**		**14**
≤ 9 employees			1			1
10 - 49 employees		1				1
50 - 499 employees	1	3	1			5
≥ 500 employees		2	4	1		7
(Bio)-chemical industry		**6**	**5**	**3**		**14**
≤ 9 employees			1	1		2
10 - 49 employees				1		2
≥ 500 employees		5	4	1		10
Consumer industries		**5**	**2**		**1**	**8**
50 - 499 employees		1				1
≥ 500 employees		4	2		1	7
Consultancy and industry networks		**2**	**7**	**4**		**13**
≤ 9 employees		1	3	3		7
10 - 49 employees		1	2	1		4
50 - 499 employees			2			2
Sum	**1**	**19**	**20**	**8**	**1**	**49**

Table A 5: Sample description of stakeholders who participated in rating process (2/3).

Stakeholder type	**Stakeholder's familiarity with SOTs**					
	not at all familiar	a little familiar	moderately familiar	very familiar	extremely familiar	Sum
Agricultural and feedstock industry		1	6	7		14
(Bio)-chemical industry		2	4	7	1	14
Consumer industries		2	2	4		8
Consultancy and industry network	1		1	9	2	13
Sum	**1**	**5**	**13**	**27**	**3**	**49**

Table A 6: Sample description of stakeholders who participated in rating process (3/3).

Stakeholder type	**Company's or consultancy's focus of SOTs' innovativeness**				
	autonomous x incremental	autonomous x radical	systemic x incremental	systemic x radical	Sum
Agricultural and feedstock industry	35.71%	25.00%	10.71%	28.57%	100.00%
(Bio)-chemical industry	32.26%	29.03%	16.13%	22.58%	100.00%
Consumer industries	35.00%	20.00%	20.00%	25.00%	100.00%
Consultancy and industry network	12.00%	24.00%	24.00%	40.00%	100.00%
Sum	**28.85%**	**25.00%**	**17.31%**	**28.85%**	**100.00%**

Table A 7: Overview of experts.

Company pseudonym	**Initial type and scope of activities**	**HQ**	**Year of start**	**Size (# employees)**	**Interviewees**
Manufacturer A	Agricultural equipment manufacturer	DE	< 1900	≥1,000 ≤10,000	Product manager; Head of crop innovation
Manufacturer B	Agricultural equipment manufacturer	US	< 1900	≥10,000 ≤100,000	Engineer; Manager Solution Controls Strategy
Chemical company A	Chemical (plant protection) manufacturer	DE	< 1900	≥10,000 ≤100,000	Head of Venture for digital agriculture
Chemical company B	Chemical (plant protection) manufacturer	DE	< 1900	≥100,000	Commercial Manager in the area of digital farming
Chemical company C	Chemical (fertilizer) manufacturer	NOR	> 1900	≥10,000 ≤100,000	Digital Agronomist, AgTech Ecosystem & Partnerships
Dealer A	Dealer	DE	> 1900	≥10,000 ≥100,000	Chief Business Development Officer Agriculture and Digital Farming
Dealer B	Dealer	DE	< 1900	≥1,000 ≤10,000	Sales consultant / machine specialist
Dealer C	Authorized Dealer	DE	< 1900	≤500	Sales consultant / service technician
Software provider	Software provider	US	> 1950	≤100,000	Sales manager Federal Government
Technology provider	Technology provider	DE	< 1900	≤100,000	Engineer; System development for software-driven systems in the field of agriculture
Start-up A	AgTech Start-up	DE	> 2015	≤10	Founder and CEO
Start-up B	AgTech Start-up	DE	> 2015	≤10	Co-founder; farmer;

					Managing Director & Head of Partner Management and Agriculture
Farmer	Farmer	DE	NA	≤10	Employee on farm
Industry association	Industry association	DE	< 2000	≤1,000 und ≥10,000 (incl. members)	Division Manager Agriculture
Consultancy	Consultancy	DE	> 2015	≤10	Founder; Expert for digitalization in agriculture / satellite data applications

Table A 8: Questionnaire.

	Analytical dimension	**Subject**	**Questions**
1	Professional and personal information of the respondent (general)	Personal questions	What is your position in the company?
			How did you get to your current position (career / motivation)?
2	Business model	Definition of Business model	What is your product, how do you create it and how do you make money? Who are you customers and suppliers?
		Impact of digitalization	How did your business model change due to the integration of digital technologies?
3	Positioning in ecosystem	Market entry barriers	Are you concerned about new entrants to the industry and what do you do against it?
		Use of valuable resources within the ecosystem	What resources are you currently most concerned about in the company?
		Value networks /Technical and personal connectivity	What is the role of value networks and interfaces between other actors within and across your industry? Did the role change in the last years?
4	Bargaining power (as outcome of business model and positioning within the ecosystem) → leads to operationalization of control points	Conflicting interests / tussles	Do you see any conflicts (and if so, which) between your company and other (new) actors in the digital agriculture / e-mobility?
		Control points of value capture / choke points	Which actors determine and influence the profit of the industry? Did this change during the last years?
		Technical and social control point	How and where do you facilitate or restrict interaction and exchange of different actors and the connection of different devices?
		Power imbalance between platform owner and its members	How is it possible to be competitive within the ecosystem while not being the orchestrator (i.e. the platform owner)?
5	Sustained competitive advantage	Role of Isolating mechanisms / Unique selling proposition	How do you try to protect your competitive advantage sustainably advantage? What do you think, how long will it last?
6	Outlook	General industry dynamics	What are the general dynamics in the industry and what does the future hold in your perspective?

Table A 9: Description and examples of control points and institutional boundaries in the digital agricultural business ecosystem.

Type	Most relevant layers	Control point / institutional boundary	Description	Examples from agriculture	Quote from the interviews
Technical	• Digital service • Analytics	Content	A critical success factor in achieving or holding a sustainable competitive advantage is to be able to control the content within the digital business ecosystem to eventually become a content gatekeeper (Pagani, 2013).	• Offering digital consulting based on satellite or other data	*“And we are also a producing company in certain areas - now in terms of software. We have developers, who produce information systems. Or, as I said, [our subsidiary], which produces digital advice based on satellite data, other data and plant growth models, and makes appropriate fertilizer recommendations for agricultural machinery.”* (Dealer A)
Technical	• Digital service • Analytics • Connectivity • Data sampling • Physical device	Modularity	This control point refers to the compatibility with other players to be able to connect different machines and digital tools. Value relies in creating modules that can be integrated in many different machines, systems or platforms. Companies want to widely spread their capabilities rather than protect them as proprietary assets (Pagani, 2013).	• Defining APIs to control which products, systems and services are interoperable • Support of industrywide standards (e.g. ISOBUS)	*"So, we are basically open, we have our own interface where partners can connect. An API is publicly accessible, and that's no secret. In this regard we are open."* (Chemical company B)
Technical	• Connectivity	Digital Infrastructure	Companies providing a digital infrastructure create value by reducing distribution, transaction, and search costs when different actors come together (Pagani, 2013). The actor especially creates value for digital service providers, as it becomes more cost-efficient and predictable to deliver digital support and control actual outcome. As potentially all actors need to use this technology to participate in the ecosystem, there is a huge potential for value capture.	• Providing enabling system technology • Providing central data hub	*[...] Accordingly, we said, "Okay, dear digital service provider, it's clear that you're going to [the big machine manufacturer] if he already has [the infrastructure]. And for the others, [...], we offer an alternative or mixed fleet, i.e. [brand A] tractor with [brand B] field sprayer or something like that. So, we're standing there and we're kind of building the android [for the agricultural industry].* (Technology provider)

Technical	• Digital service • Analytics • Physical device	Data*	Creating value by summarizing, holding and evaluating data in a central location. As many actors have to pass this control point, there is a huge potential for value capture.	• Having data sovereignty • Having unique and high-quality data	*"The greatest value emerges if I can summarize, hold and evaluate the data in a central location."* (Software provider)
Technical	• Digital service • Analytics • Connectivity	Scalability*	Having a product or process which is scalable lead to increasing value capture in the future. For instance, for digital service providers, this control point might be enabled by the availability of a "digital infrastructure".	• Fast scalability of digital services • Develop once, deploy anywhere	*"We cut all machines at the bottom and separate functions from machines. This means "develop once, deploy anywhere". This is an old Java saying, which means that the marginal development and sales costs tremendously decrease, because the platforms are no longer considered individually, but as a whole. In business terms, the investment in the platform is divided among many, many services."* (Technology provider)
Technical	• Digital service • Analytics • Connectivity • Data sampling • Physical device	(Unique) solution*	Having (unique) technical solutions either restricting other to do the same or enabling a unique benefit at the customer front-end. Thus, value is created by unique features and value is captured by customers appreciating unique products and services.	• Intellectual property restricting others to do the same • Providing holistic solutions across product life cycle	*"We are moving more and more in the direction of offering solutions to problems, for example water shortage or carbon farming. Stories like that."* (Dealer A)
Strategic	• Connectivity • Physical device	Orchestration	With increasing modularization, the ability to coordinate between (orchestrate) modules and various actors across value chains and industries becomes valuable for creating a common EVP and hence obtaining a central ecosystem position (Pagani, 2013).	• Aggregating various actors and creating the new market • Platformization	*"We have to be neutral and open to all players, so that everyone has confidence in us. And none of the players will develop the market themselves, but the orchestrator will have the difficult task of first creating the market, then bringing the players to the table, then motivating the players, and then pampering them so that they join in. And it means very high risks."* (Technology provider)

Strategic	• Digital service • Analytics • Connectivity • Physical device	Networking	Networking is a strategy to establish the "right" connections to partners and also competitors to guarantee participation in the digital business ecosystem game (Van Dyck et al., 2021).	• Cooperate with start-ups • Cooperate with partners (e.g. competitors) to attract more users	*"[...] strategic partnerships that are developed. That means sitting at the table with the right people and then getting the chance to establish your product or service. Because in the end, many small companies do something. They all offer a service somehow. And that works on a small scale. But how can it be integrated into the big playground? And for that you need a partner who allows it. And if it then works, then it is also accepted. And I think there is a hurdle. How do I get in to this door?"* (Start-up A)
Strategic	• Digital service • Analytics • Connectivity • Physical device	Customer access	In digital business ecosystems value is increasingly created at the end of the network, namely the customer. Customer access allows highly customized connections leading to value creation for and with the customer (Pagani, 2013; Van Dyck et al., 2021).	• Physical customer close to the farmer while being able to provide support on the field • Digital customer access while providing access to digital platform	*"Technical problems that have different causes have to be solved. In theory, this could be done remotely, but it's also a matter of trust. The farmer says "come when there's a problem". If this "digitization" is again not working, someone taking care of it is a huge factor."* (Dealer A)
Strategic	• Digital service • Analytics • Connectivity • Data sampling • Physical device	Brand	Having or establishing a powerful brand reputation leads to customer lock-in effects and potential for more value capture (Van Dyck et al., 2021).	• Long established brand of machine manufacturer	*"some people love brand A, others brand B, next one other machine manufacturers. In this case, love means trust. And I believe that once they are with one of them, they will stick with it."* (Consultancy)
Strategic	• Digital service • Analytics • Connectivity • Physical device	Know-How*	Know-how encompasses various layers of expertise, which are necessary to compete in the digital business ecosystem. It is important that companies are aware of their respective expertise and know-how the market of the emerging digital business ecosystem works.	• Having knowledge about the users and how to talk with them • Having agricultural know-how and competencies in agronomic analysis	*"You simply have to say that the expertise we bring to the table in this area means that one thing adds to another. Because the customer knows that we are basically fit in this area, the customer approaches us. The sum of the orders then ultimately leads to the amount of profit."* (Dealer B)

Strategic	• Digital service • Analytics • Connectivity • Data sampling • Physical device	Agility*	The control point agility encompasses spotting and creating new value creating sources faster than competition. The decision to be early in investing in R&D advancing digital technologies and being agile in reacting to customer requirements may protect or foster a company's competitive advantage.	• Responding quickly to customer requirements • Being pioneer on the market, i.e. first mover	*"And one issue is and this is definitely an issue also in our restructuring: we want to act faster and more customer-oriented."* (Manufacturer B)
Strategic	• Digital service • Analytics • Connectivity • Data sampling • Physical device	Financial Resources*	Financial resources provide a point of control when it comes to having the flexibility to try out different markets and prove reliability to partners.	• In large cooperation parent companies may compensate for losses in digital division • Financial solvency can demonstrate reliability	*"So [our company] is a very, very financially sound company. If the farmer does business with us, he can pretty much rely on the fact that he can also sell his used agricultural machinery back to us in 6 years or that he will get his grain money and so on."* (Dealer A)
Institutional	• Digital service • Connectivity • Physical device	Market design*	The state may have the control to design the market (incl. setting certain standards and rules), which is addressed by the digital business ecosystem. Other (prevailing) regulations are also set by institutions, which eventually may have an impact on the value creation and distribution among business ecosystem participants.	• Data frameworks and digital infrastructure (e.g. GaiaX) • (Prevailing) regulation, policies for agriculture (e.g. data protection, traffic regulations)	*"And yes, I am convinced that this central decision is needed. Whoever provides the technology at the end of the day is, again from my point of view, a decision that has to be made, but I believe that this central unit is needed because otherwise, we will see what I believe is already beginning to emerge. It's going to be a big battle of the big industry drivers as to who can prevail at the end of the day. And at the end of the day, the public sector will have to accept what's there, because at the end of the day, it may simply be too late to set the agenda, as much has already been established in the market that you simply can't turn back certain things."* (Software provider)

Institutional	• Digital service • Connectivity • Data sampling • Physical device	State intervention*	This institutional boundary refers to the active institutional intervention in the digital business ecosystem promoting the use of digital technologies and facilitate data accessibility.	• State is subsidizing use of digital technologies. • State providing central access to open data and free software	*“The [German] coalition agreement states that there is to be an agricultural platform, a state platform at the federal level. That is what we have demanded by central access to services, a central access to open data and what is not included yet but is important would be to provide connection possibilities for software and IT services from companies. And we just hope or I hope that this is now also pushed forward and I believe that this would be a huge opportunity. A platform where the farmer can log in, where he can get all kinds of data, where he can then submit his farm management program, the agricultural applications, the reports and the like. That would be enormously helpful.”* (Industry association)

Remark: Control points and institutional boundaries marked with an asterisk have been emerged as new categories previously not reported as particular control points in digital business ecosystem literature.

Definition of sustainable technologies:

Ecologically sustainable technologies generally fall into two categories: End-of-pipe technologies and clean technologies. End-of-pipe technologies are often used in response to stricter environmental regulations to reduce the negative environmental impacts of business activities. Clean technologies, on the other hand, take a more holistic approach by addressing the source of environmentally harmful production methods, thereby reducing the environmental impact of the production process itself.

A variety of sustainable technologies can be found, for example, in the field of biotechnology (e.g., enzymatic resource recovery or substitution of fossil resources by renewable resources) as a cross-cutting technology for different industries. Therefore, in the context of this study, we are interested in the perspective of different stakeholders along the value chain of industrial biotechnology.

Figure A 1: Introductory definition of SOTs for stakeholders participating in discussion, rating and sorting process.

Instruction:

Your task in our study consists of two steps: 1. sorting and 2. rating. The first step is to intuitively group the following 59 statements regarding the selection criteria of sustainable technologies from a business perspective - i.e. each statement is a completion of the Focus Prompt "Selection criteria for new sustainable technologies from a business perspective are...". You are to sort statements that you think are similar, or deal with a similar issue, into so-called "Categories". First, please read through the list of unsorted statements. By clicking on "Add New Category" you can then create new categories into which you can sort the statements. There is no right or wrong classification here, it is all about your intuitive perception of the statements. In addition, please give each category a name.

You may assign individual statements to a stand-alone category if there is no connection to other statements. Please make sure you have assigned each statement so that no statement remains in the list. It is entirely up to the individual how many categories seem necessary or useful to group the statements. Normally, however, this number of statements results in between 5 - 20 categories.

Please do NOT create a group "Other" or "Others" with statements that you cannot assign. In this case, open a new category instead. Categories should be based on similarity of content, not on your rating, such as "importance" or "relevance." This step follows in the second step of this study.

Figure A 2: Instruction to stakeholders participating in the online sorting and rating process.

Relevance of selection criteria

When evaluating (sustainable) technologies, what priority do the following criteria have in your decision-making process? Please rate on a Likert scale from 1 to 5 how relevant each selection criterion is to your company.

1) not relevant at all
2) somewhat relevant
3) moderately relevant
4) relevant
5) very relevant

Figure A 3: Instruction to rating process.

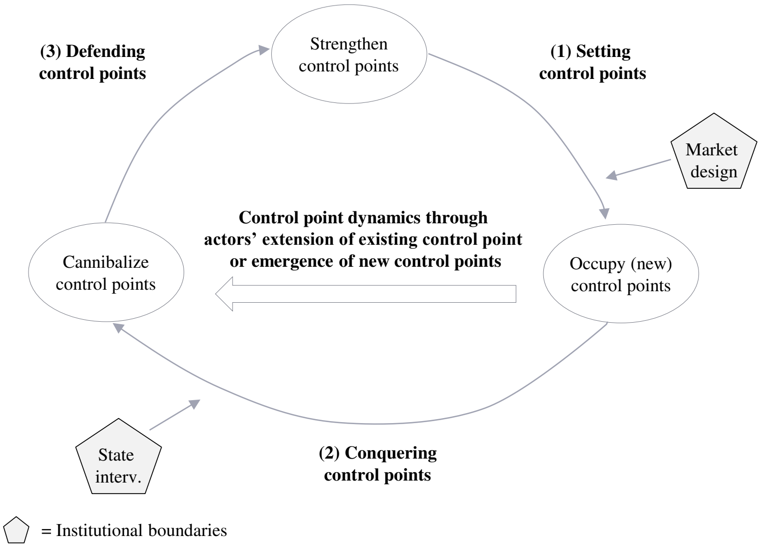

Figure A 4: Evolutionary process of setting and shaping control points to achieve a competitive positioning.