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RESEARCH ARTICLE

Selecting technologies to engage in sustainability transitions— A multi-stakeholder perspective

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Abstract

Given the need for systemic changes to reach a sustainability transition from a fossil-based toward a bio-based economy, it is crucial to align different actors' expectations along the value chain when developing and commercializing sustainability-oriented technologies (SOTs). To analyze 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, that is, (1) agricultural and feedstock, (2) (bio)chemical, (3) consumer industries, and (4) consultancies and networks. We derive 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 acceptance, and the sustainability aspects of the technology are perceived as highly relevant for most actors when selecting SOTs. Further, we summarize the 11 categories into four dimensions involving (1) market environment and viability, (2) corporate strategy and technology integration, (3) capabilities and knowledge exchange, and (4) institutional and regulatory frames related criteria. We contribute to sustainability transition literature by providing, first, a conceptual framework for relevant selection criteria of SOTs from a value chain spanning perspective; and second, areas of coherence versus noncoherence in technology evaluation across different value chain actors allowing targeted support initiatives to facilitate the technology transfer in the context of sustainability transitions.

KEYWORDS

bio-based economy, business stakeholder, group concept mapping, sustainability transition, technology selection

Abbreviations: GCM, group concept mapping; GMO, genetically modified organism; LCA, life cycle assessment; R&D, research and development; RQ, research question; SDG, Sustainable Development Goal; SOT, sustainability-oriented technology.

All authors declare that they have no conflicts of interest.

1 | INTRODUCTION

Sustainability is the imperative across all industries (Loorbach & Wijsman, 2013; Rigall & Wolters, 2019) accompanied by long-term

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and multidimensional 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 toward 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 toward 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, for example, 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 is 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, that is, 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 et al., 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 et al., 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, that is, 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).

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?

RQ2. 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 toward 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 toward 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 toward 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 et al., 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 toward 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).

2 | THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1 | SOTs

Within the concept of eco-innovations, SOTs can be categorized as technological innovations that reduce the firm's activities' impact on the environment (Rabadán et al., 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, that is, autonomous versus 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).

Besides 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 & Strebler, 2013). However, in order to achieve the technological substitution pathway and thus the replacement of the old socio-technical regime, that is, 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 1 exemplarily illustrates various emerging value chains in this bio-based economy, which go along with systemic changes.

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 toward 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 et al., 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 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

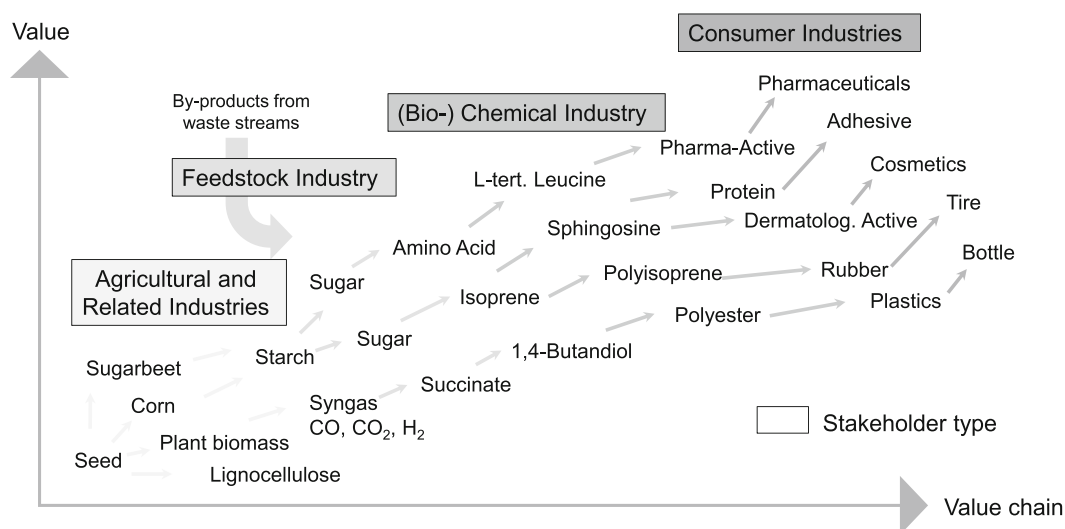


FIGURE 1 Exemplary value chains and industry stakeholders in the bio-based economy. Source: Based on Kircher (2012)

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, for example, 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, for example, 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, for example, academia, industry, or policy on different levels of perspective, that is, niche, socio-technical regime, or landscape level, when analyzing transition processes (Geels & Schot, 2007). However, a value chain, that is, cross-industry perspective, in evaluating SOTs is still neglected.

Following from the abovementioned 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 et al., 2020). Technology selection is a complex, multi-criteria decision problem for companies, which especially applies for technology-based companies (Ma et al., 2013). We argue that the systemic character of SOTs adds even another layer of complexity, as coevolution 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.

2.3 | Technology selection criteria

Technology selection is part of the bigger innovation process starting with technology scanning, selection, and adoption until exploitation (Shehabuddeen et al., 2006). The selection decision, however, is very

challenging as it may involve foresight, dynamics, ambiguity, and prudence (Zhao et al., 2022). The technology selection is even more challenging when considering emerging technologies (Rotolo et al., 2017). Following the framework of industrial emergence by Phaal et al. (2011), this paper focusses on technology selection within the science- and technology-dominated emergence phases toward 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 et al., 2019) or biotechnology (Kharat et al., 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, that is, 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 et al. (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 toward 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 et al.'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

TABLE 1 Overview of potential technology evaluation and selection criteria

Dimensions	Criteria (respective examples)	Focus/reference
Technical Economic Environmental Social	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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 Systematicness Maturity	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Technology maturity • Competitive advantage • Necessary business skills 	Technology transfer evaluation (Cartalos et al., 2018)
Technical Process Economic Market Perception Regulatory/policy	<ul style="list-style-type: none"> • Technical feasibility • Implementation requirements • Capital requirements • Market demand • Risk aversion • Incentives 	Emerging technology and technology transfer evaluation (Jain et al., 2003)

Note: 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.

innovation financing. Jain et al. (2003) provide a set of six dimensions according to which emerging technologies and their transfer potential can be evaluated.

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 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, that is, 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 | RESEARCH DESIGN: GCM

3.1 | Overall study approach

We follow the research design of 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 et al., 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 2) and introduce the chosen case of the bio-based economy (cf. Figure 1).

3.2 | Preparation

In Step 1 (cf. Figure 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, for example, 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 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

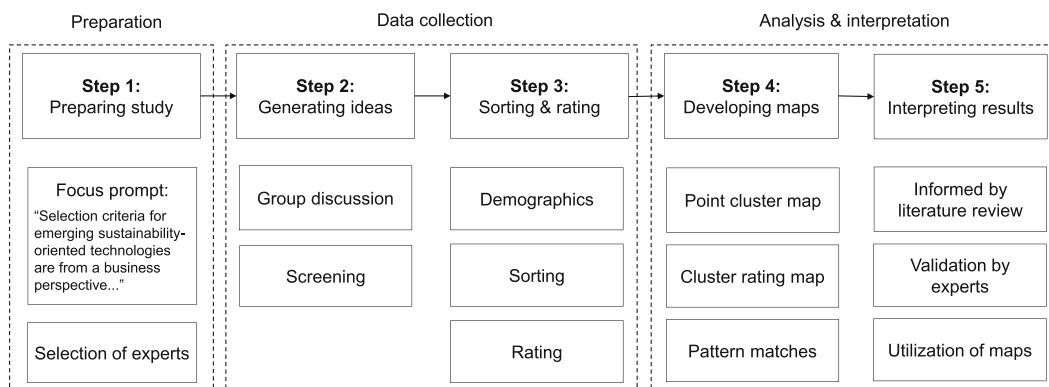


FIGURE 2 Steps of the group concept mapping study. Source: Based upon Kane and Trochim (2007).

experts except one located in Switzerland, work for organizations located in Germany.

3.3 | Data collection

Steps 2 and 3, the data collection, consist 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 12 predefined participants, one person dropped out during the online discussion and did not contribute to the discussion. Thus, 11 experts (participants) are listed in Table 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).

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 versus exploitation (Cillo et al., 2019) while selecting SOTs. The workshop including introduction and closing took 3 h. The actual group discussion took 1.5 h, 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 *groupwisdom*. 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 A1) 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 A2 to A4). 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

TABLE 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	

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.¹ One stakeholder represents a distinct company or strategic business unit within an organization. The detailed breakdown of the participating stakeholders is presented in Table 3. More information on the participating stakeholders can be found in the Appendix A in Tables A2 to A4.

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, that is, 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

¹It should be noted that one out of these 49 participants only rated 58 out of 59 statements.

TABLE 3 Profiles of participants. Source: Authors

Stakeholders' industry origin	Sorting statements (n = 40)		Rating statements according to relevancy (n = 49)	
	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

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 toward 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 is 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.

4 | RESULTS

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

Figure 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

TABLE 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

TABLE 4 (Continued)

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
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
Economic viability		3.97	4.04	3.73	3.93	4.18	0.037
4	Their economical 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

(Continues)

TABLE 4 (Continued)

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
	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
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

TABLE 4 (Continued)

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
	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
48	The presence of legal framework conditions for authorization and application, which were set by policymakers	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

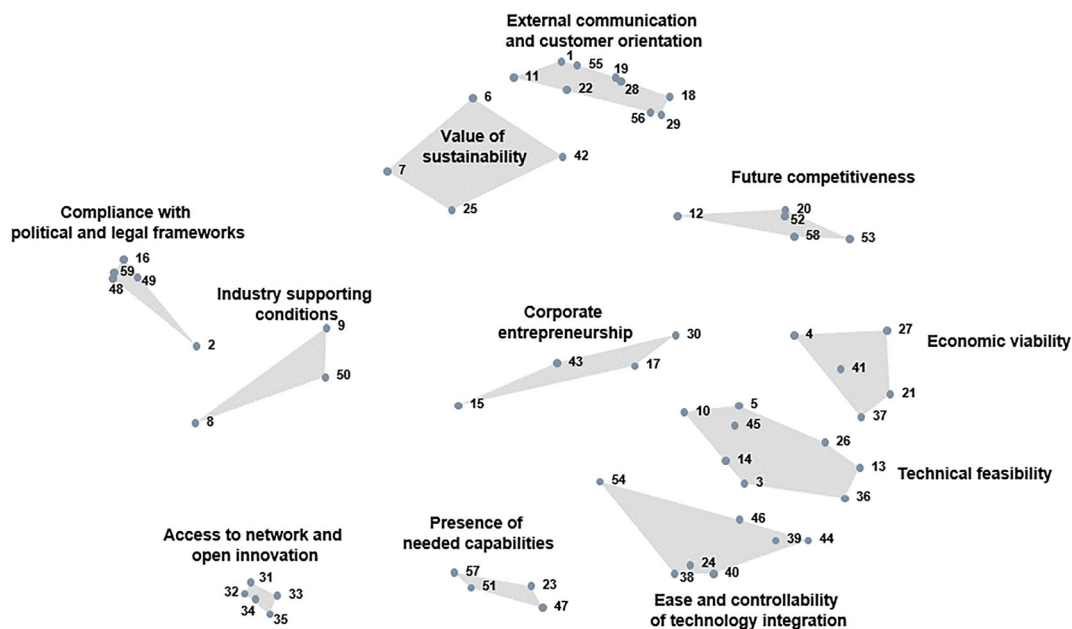


FIGURE 3 Point cluster map for the 11 clusters with their respective labels

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 afterward. 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.

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 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 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 5, as for this purpose, they cannot be directly allocated to a certain position in the value chain. The pattern matches in Figure 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*

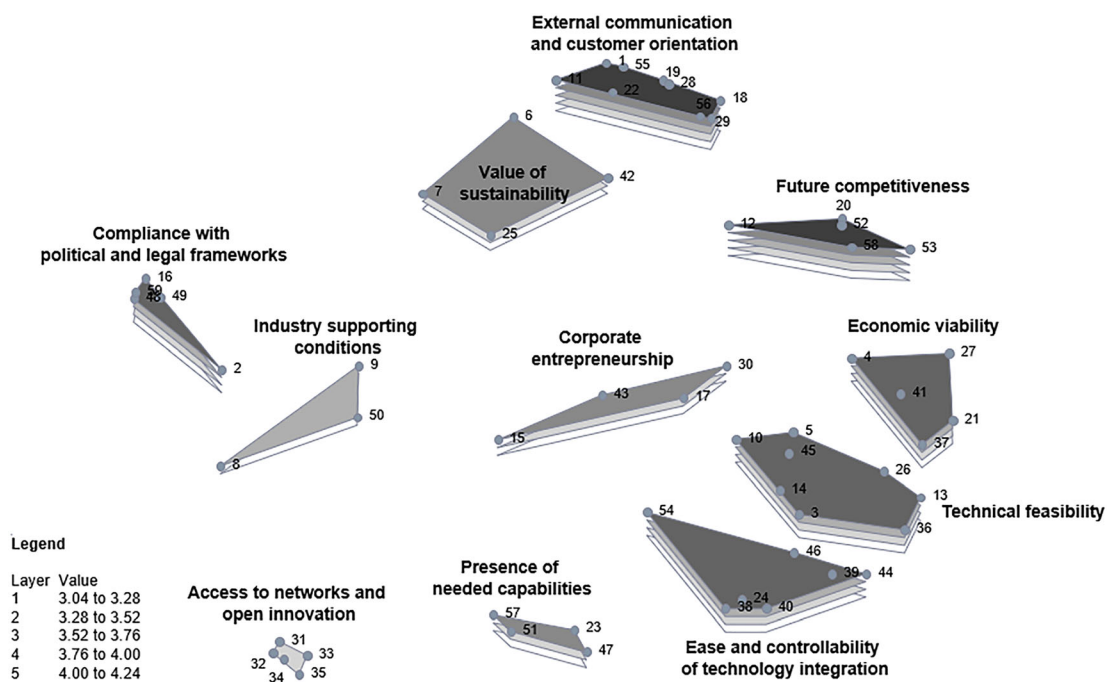


FIGURE 4 Cluster rating map with the average ratings of relevancy. Note: Ratings are based on a 5-point Likert scale.

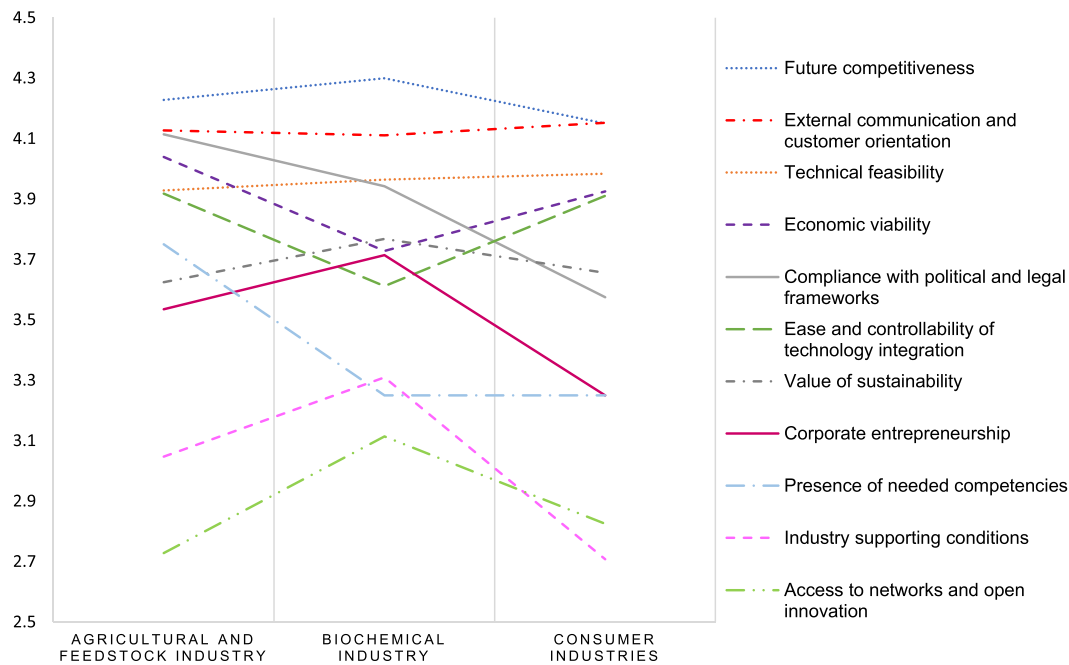


FIGURE 5 Pattern matches—average relevancy along the value chain of the bio-based economy

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.²

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 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 et al. (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 et al., 2017; Teece et al., 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).

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 et al., 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 concerns are criteria, which are especially mentioned in the context of SOTs (Visser et al., 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 et al., 2016). Compared to existing literature on technology selection criteria, the cluster *value of sustainability* contains new criteria, which are particularly relevant for the

²The 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.

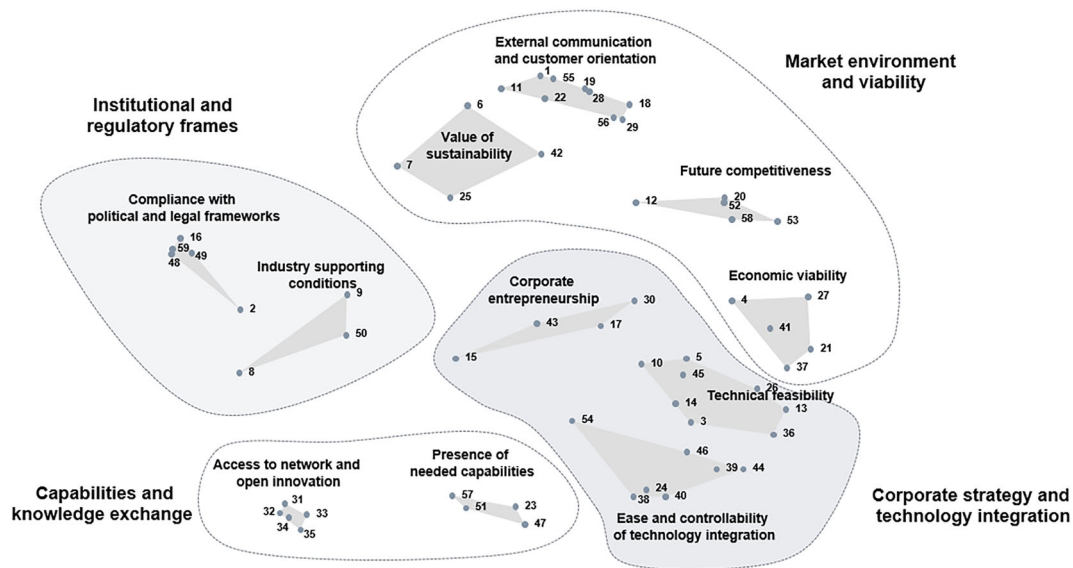


FIGURE 6 Four overarching dimensions for the evaluation of sustainability-oriented technologies

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 et al., 2020), our study shows that it is important for stakeholders throughout the value chain that there is a proof of a true sustainability confirmed, for example, 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 *future 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 et al., 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 *technical 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 intraorganizational collaborations (Messeni Petruzzelli et al., 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 et al., 2021). Leendertse et al. (2021) found that depending on the type of technology, that is, physical versus 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, that is, 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 5. However, Table 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, that is, industries. Also, *access to networks and open innovation* are perceived as more relevant by consultancy and networks, which were 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 et al., 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, that is, 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 are more relevant for those resulting from radical innovations.

6 | CONCLUSION

Sustainability transitions from a fossil-based toward 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, that is, (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.

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, for example, 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, for example, 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 versus noncoherence 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 multidimensional 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 (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).

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 highly relevant technology selection criteria for all stakeholders, the entire customer experience should be incorporated by, for example, 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 toward 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 et al., 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 sidestreams of production processes and value chains, several start-ups are already using these digital technologies (see e.g., Ellen MacArthur Foundation, n.d.). 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.

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 SOTs 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 et al., 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.

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 toward a bio-based economy or the concept of circular economy (Di Maria et al., 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, 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, eight 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 multinational 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 et al., 2020) or case studies might be conducted (Lee & Kim, 2011; Stalmokaitė et al., 2022). Also, larger surveys could validate the constructs we created and elaborate on indicators measuring the technology selection criteria.

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APPENDIX A.

TABLE A1 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.	<ol style="list-style-type: none"> 1. Agricultural raw material 2. Chemistry/biotechnology (mainly B2B) 3. Food industry (mainly B2B) 4. Consumer goods (e.g., personal care, food, cosmetics, and textile) 5. Consulting/industry network
2	Company size	How many employees does your company have?	<ul style="list-style-type: none"> • ≤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?	<ul style="list-style-type: none"> • 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?	<ul style="list-style-type: none"> • 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?	<ul style="list-style-type: none"> • 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

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 A1 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 A2 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 A3 Instruction to rating process**TABLE A2** 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 feedstock 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 A3 Sample description of stakeholders who participated in rating process (2/3)

Stakeholder type	Stakeholder's familiarity with SOTs					Sum
	Not at all familiar	a little familiar	Moderately familiar	Very familiar	Extremely familiar	
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 A4 Sample description of stakeholders who participated in rating process (3/3)

Stakeholder type	Company's or consultancy's focus of SOTs' innovativeness				Sum
	Autonomous × incremental	Autonomous × radical	Systemic × incremental	Systemic × radical	
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%