Sustainable business model innovation

Design guidelines for integrating systems thinking principles in tools for early-stage sustainability assessment

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A R T I C L E I N F O

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A B S T R A C T

The need to develop sustainable business models, which have a positive effect on environment and society, has received increasing attention in research and practice in the last years. Describing the sustainability of these business models, however, often takes place without robust assessments and without consideration for the wider system within which they are embedded. Early in the innovation process, in particular, a lack of quantitative data, time, and competencies presents an issue. At the same time, Systems Thinking has long been described as necessary for innovating business models for sustainability, but it has not been made clear how exactly Systems Thinking can be used early in the innovation process to assess the sustainability of a business model innovation. This article develops guidelines for embedding Systems Thinking principles into tools for sustainability assessment for use in the early stages of sustainable business model (SBM) innovation. It does so by exemplifying Systems Thinking principles in the context of SBM innovation and analysing their integration in three selected tools for early-stage sustainability assessment. The article shows how, by embedding Systems Thinking into tools for the SBM innovation process, unintended consequences and negative trade-offs can be reduced and the sustainability of the innovation better understood. Eight design guidelines are proposed for effectively using Systems Thinking in tools for early-stage sustainability assessment of SBMs: (1) Define scope of application, (2) Design for collaboration, (3) Integrate the principles “Interconnections”, (4) “Causal relations & feedback loops”, and (5) “System change & adaptation”, (6) Consider sustainability dimensions, (7) Ensure flexibility of integration, and (8) Ensure compatibility with other assessment tools.

1. Introduction

The concept of sustainable business models (SBM) has received widespread attention in both research and practice, with significant public funding underpinning the development of numerous SBM programs in recent years. SBMs are typically seen as a way to generate revenue while reducing the overall environmental impact of a business or service, and/or increasing its social benefits (Kaplan, 2012; Løkke et al., 2020; Lüdeke-Freund et al., 2018; Schaltegger et al., 2016). Despite this key purpose to pivot businesses towards improved social and environmental sustainability, a key challenge related to SBM innovation remains the assessment of their impact.

Proposals focusing on integrating and assessing economic, social, and environmental sustainability in SBMs are relatively few, which led Bocken et al. (2016) to state that *“currently, it is unknown what the potential positive (or negative) impacts of such new business models could be”* (p. 4). A crucial element in assessing the sustainability of new business models is to acknowledge the interconnectedness of business activities within the company, while recognizing that a business model is connected to, and influenced by, other initiatives within a wider system (Boons and Bocken, 2018; Bocken et al., 2019). The systems perspective and understanding are argued to be of increased importance when innovating for sustainable business models (Løkke et al., 2020; Mortensen and Kørnøv, 2019). This is due to the interconnectedness of society’s problems: *“When we look at the state of the world today, what is most evident is the fact that the major problems of our time – energy, the environment, climate change, food security, financial security – cannot be understood in isolation. They are systemic problems, meaning that they are all*

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interconnected and interdependent" (Capra and Luisi, 2014, p. 362).

The term 'Systems Thinking' refers here to a holistic approach to individual business initiatives where these are analysed based on their (internal and external) systematic consequences in relation to a company. Systems Thinking and its principles is widely applied within sustainability management research (Williams et al., 2017) and is specifically acknowledged for explaining the importance of contextual boundaries of SBM innovation (Shakeel et al., 2020). Not considering system's effects outside the boundaries of the company can lead to SBMs being assessed without due consideration for the interdependencies which exist within increasingly complex value-chains, which may result in discrete and often limited assessments of sustainability. If actors involved in the business model development do not critically assess both the wider potential positive and negative contributions to sustainability, a business model may lead to unintended trade-offs and be wrongly perceived as sustainable. In some cases, limited assessments of sustainability may even lead to greenwashing with *"[…] misleading communication about environmental activities or performance"* (Bowen and Aragon-Correa, 2014, p. 107).

Application of System Thinking theory to business model innovation can be explored in different ways: Brainstorming techniques are based on simple templates, whilst more complex applications include formal model building, complex diagramming, and statistical expertise (Alter, 2011). However, researchers, such as Alter (2011) call for new and straightforward tools for sustainable business model innovation (SBMI), that build on Systems Thinking, i.e., tools which are accessible for practitioners and can thus help ensure a systemic view of SBMs and their associated sustainability. This is especially important in the early stages of SBM innovation, in which details on potential solutions are not decided upon.

Pieroni et al. (2019) argue that "*the majority of methods and tools still adopt[s] organizational boundaries"* and that future research should *"explore how to take inter- organizational or societal boundaries into account"* (p. 210). Bhatnagar et al. (2022) highlight the systems perspective as a central principle for designing tools for SBM sustainability assessment, but it has not been systematically explored how Systems Thinking is, and can be, integrated into sustainability assessment conducted in the early stages of SBMI.

To address this call and research gap, this study investigates selected tools for SBM innovation. It analyses how System Thinking principles can be used in the design of these tools and provides guidelines for future easy-to-use tools for sustainability assessment.

The study builds on the following research question: *What guidelines should be followed in integrating Systems Thinking into the design of tools for early-stage sustainability assessment of SBM innovation?*

Thereby, this article takes its outset in Systems Thinking (ST) theory and combines it with an analysis of practical operationalizations as put forward by Alter (2011). Although Systems Thinking theory has its origin in a structural-functionalist ontology that at times is criticised for its lack of intrinsic orientation towards change (Geels, 2010), we aim at operationalizing abstract Systems Thinking principles and show how they can facilitate change.

The results show that Systems Thinking can assist the sustainability assessment of SBMs in early stages of the innovation process. The analysis highlights that this can be enabled by appropriate tool design and eight design guidelines are recommended: (1) Define scope of application, (2) Design for collaboration, (3) Integrate principle "Interconnections", (4) Integrate principle "Causal relations & feedback loops", (5) Integrate principle "System change & adaptation", (6) Consider sustainability dimensions, (7) Ensure flexibility of integration, and (8) Ensure compatibility with other assessment tools.

The article is structured as follows. In section 2, the state of the art presents three core Systems Thinking principles, which form the theoretical point of departure, outlines how SBM research currently considers business models from a systems perspective, and shows the tool landscape in the early stages of SBM innovation. Section 3 describes the methodology. Section 4 first presents the translation of ST principles to SBMI practice and the analysis of the selected tools. Then, the guidelines for integrating ST principles in early-stage sustainability assessment for SBM innovation are discussed. Section 5 provides concluding remarks and suggestions for future research avenues.

2. State of the Art: Systems Thinking for sustainable business model innovation

2.1. Systems Thinking: theoretical point of departure

Systems Thinking is a paradigm as well as a learning method (Senge, 1990), viewed either as a means of providing insight into systems which goes beyond basic modelling and which encompasses the elements of Systems Dynamics (Senge, 1990; Richmond, 1994), or as a subset of, and 'door opener' to, the System Dynamics discipline (e.g. Forrester, 2010).

Systems Thinking definitions tend to repeat certain elements (Arnold and Wade, 2015), which include 1) interconnectedness among systems elements, 2) causal relations and feedback loops between them, and dynamic behaviour, including emergent behaviour, which requires 3) adaptation. These core principles of Systems Thinking are introduced in the following.

2.1.1. Interconnectedness

Systems Thinking perceives the world as various elements and constituent parts that are interconnected and organized in specific hierarchies to form complex systems (Hildebrandt, 1983). The group of parts or elements forming a system are interconnected with a myriad of relations through which they can function together (Colchester, 2016). This set of elements *"is coherently organized and interconnected in a pattern or structure that produces a characteristic set of behaviours, often classified as its function or purpose"* (Meadows, 2009, p. 188). The interactions between the parts of a system produce relationships perceived with specific and real content (e.g., material flows) or abstract content (e.g. friendship relations) (Colchester, 2016).

A system can be closed – where the components of a system do not have any relation with an outside environment — or open, i.e., in relation with the environment the system is a part of (Hildebrandt, 1983). An open system is embedded in a larger context and *"system and environment comprise an interactive process"* (Hammond, 2017, p. 13) and influence one another in a co-evolving process. The elements are the building blocks of a sub-system, and sub-systems are building blocks for a larger system. The system boundaries thus represent the delimitation of a sub-system from its larger system (Boardman and Sauser, 2013). Being interrelated, the development of each element is influenced by the other elements in a network, and the evolution of a sub-system depends on the evolution of other sub-systems of a larger system. A sub-system changes and co-evolves (Kauffman, 1993 in Nooteboom, 2007) *"in communication with other sub-systems, […] where the change is determined by the interplay between the characteristics of a subsystem and the changes of its environment"* (Nooteboom, 2007, p. 648). The number of elements within a system, the diversity among these, and their degree of interconnectivity characterizes the complexity of a system (Colchester, 2016).

An example of the fundamental nature of interconnectedness is shown by the role of stocks and flows within a system (Weinhardt et al., 2015). Stocks are entities that either accumulate or deplete, for example, a bathtub of water, while flows represent the entities that cause stocks to either increase or decrease, in this case a faucet or drain (Gonzalez and Wong, 2012). Stocks and flows therefore form the intrinsically interconnected infrastructure typical of a system, one which also provides the basis for *causal relationships and feedback loops* to exist (Richmond, 1994).

2.1.2. Causal relationships & feedback loops

There are cause-effect relationships between different parts of a system. One part of a system (an event, process, state, or object) is the cause, which affects another part, representing the effect. While there might be a variety of causes and effects, each cause is at least partly responsible for the effect, and the effect is partly dependent on each cause. In linear relations, the change of the output is proportional to the change of the input; in non-linear relations it is not. The latter is more common in complex systems (Waltner-Toews et al., 2008). Cause-effect relationships can be described through uni-directional chains of causal relationships, but interrelations of parts can also be taken into account by relying on the use of causal networks (Niemeijer and de Groot, 2008). Understanding causal networks helps understanding rebound effects, meaning the reduction in expected positive impacts due to behavioural or other systemic responses (e.g., efficiency improvements that lead to cost reductions, which in turn lead to increased consumption of a product (Thiesen et al., 2008)).

Moreover, there are closed causal chains, which create feedback. Feedback loops are self-perpetuating pattern, in which the end result reinforces the initial cause. Feedback loops thus illustrate how an effect (B) is not only caused by a cause (A) but will in turn also affect A in various ways. They can be of positive or negative nature, where "*a positive feedback enhances the effect; a negative feedback dampens it*" (Walker and Salt, 2006, p. 164). Boardman and Sauser (2013) specify that positive feedback accounts *for "both healthy growth -or a virtuous cycle - as well as retrenchment - or a vicious cycle"* (p. 21). Even though this inertia can be beneficial in cases where development goes in the desired direction, positive feedback loops tend to cause system instability. In negative feedback loops, the outputs mute or moderate the initial inputs. They have a dampening effect on the initial cause and generally promote stability.

In a system perspective, the feedback will be determined by a time lag governed by the reinforcing loops (or consequences) arising from the interconnectedness between the systemic parts.

2.1.3. System change & adaptation

"Socio-ecological systems are constantly changing" (Folke et al., 2002, p. 8) and the previously described interrelationships and feedback loops give rise to constant system changes. Dynamic behaviour within a system is created by interconnections, the way they combine into feedback loops, and the way these feedback loops influence and consist of stocks, flows and variables. Positive feedback loops, for example, might accelerate towards extreme value and damage or destroy the system (Zeigler et al., 2000). Emergent behaviour, a term used to describe unanticipated system behaviour, is one example of dynamic behaviour (Arnold and Wade, 2015).

Systems change as a consequence of their surroundings, and this constant change challenges the understanding and control of the system because the system represents a dynamic entity or a *moving target* (Holland, 1992). As elements within the system change, the relationship among these changes, and thus the system changes. It adapts to the new structure and order of its elements based on their interconnectivity. Relationships and interactions between a system's elements, as well as between the system and its environment, can produce change across the system creating feedback loops among the system's elements. Despite the high complexity and challenging predictability, this dynamic nature of systems calls for ongoing learning and adaptation, and long-term planning (Kopainsky et al., 2011).

Folke et al. (2002) discuss the role of adaptive management as being closely related to learning and adaptation: *"Adaptive management proceeds by a design that simultaneously allows for tests of different management policies and emphasizes learning as we use and manage resources, monitoring and accumulating knowledge on the way, and constantly adjusting the rules that shape our behaviour to match the dynamics and uncertainty inherent in the system"* (p. 45). They hereby underline the need for monitoring in order to create the necessary understanding of such dynamics, which is supported by Løkke and Madsen (2022), who point to the need and potential for monitoring system performance in sustainable smart production and design.

2.2. Systems Thinking in sustainable business model research

The notion of businesses being embedded in a system spanning across organizational boundaries is not new. The Relational View long described how a firm's critical resources may span firm boundaries and how interfirm resources and routines may be a source of competitive advantage (Dyer and Singh, 1998). Even Systems Thinking has been made use of, to make sense of organizational questions and issues. It has for example been described as the cornerstone of the learning organization (Senge, 1990) and used in research on organization learning systems (Bontis et al., 2002).

In contrast to traditional theories of management, in which value creation is perceived as a supply-side phenomenon, definitions of business models typically include a look beyond the boundaries of a firm. This is, however, often limited to a supply-chain perspective. In contrast hereto stands an understanding of the business model concept, in which value is also seen to be created by customers and other members of their value-creation ecosystems (Brehmer et al., 2018).

2.2.1. Sustainable business models as systems

Although definitions vary, sustainable business models are seen as a way to generate revenue while reducing the environmental impact and/or increasing the social benefits of the business in question (Lüdeke-Freund et al., 2018; Schaltegger et al., 2016). The ways in which SBMs emerge, such as via diversification or the transformation of an existing BM, are referred to as sustainable business model *innovation* (SBMI) (Geissdoerfer et al., 2018).

Research has shown how Systems Thinking can support SBMI and address sustainability within organizations and across business settings (Kralj, 2009; Porter, 2008; Shireman, 1999). Based on a review of management literature, Williams et al. (2017) state that the adoption of ST in business operations design can improve an organisation's sustainability indicators. Moreover, Jaaron and Backhouse (2019) showed how there is a positive relationship between applying ST principles and the environmental performance and social benefits of employees and customers.

Researchers have also investigated different kinds of SBMI to create archetypes (Bocken et al., 2014) and patterns (Lüdeke-Freund et al., 2018) describing distinct approaches for improving business model sustainability (such as *'waste as resource'* or *'consumer education'* innovations). The rationale behind archetypes is that firms *"need to incorporate most, if not all types of SBM innovations"* (Bocken and Short, 2021, p. 11). But, ultimately, organizations can only be sustainable when the entire system, which they are part of, is sustainable (Jennings and Zandbergen, 1995), as "*changes to the socioeconomic system, both structural […] and cultural […], are required to facilitate firm-level and system-level sustainability*" (Stubbs and Cocklin, 2008, p. 122).

This problematic of innovating business models for sustainability within unsustainable systems has wide-ranging implications for SBM research: One is that current definitions of a business model's *sustainability* tend to be relative rather than absolute and take the previous business model or similar business models in the industry as the basis for comparison. Another is that definitions of SBMs seem to have a stronger stakeholder perspective (Velter et al., 2020) and a crucial trait of a SBM is described to be the aligning of *"interests of all stakeholder groups, and explicitly consider the environment and society as key stakeholders"* (Bocken et al., 2014, p. 44). Lastly, a consequence is that systems and boundaries of SBMs can be understood and applied in different ways (Pieroni et al., 2019), often varying between an organizational, inter-organisational, and societal scope. The systems may concern social systems (Neumeyer and Santos, 2018), business networks (Boons and Bocken, 2018), as well all as technological and ecological systems.

From our perspective, SBM innovations that revolve around one or several focal firms can therefore be considered a component of a larger societal transition, or system, towards sustainability. An integration of the company and system level is needed (Koistinen et al., 2018), where continuous attention to system boundaries to *"deliver sustainability"* is required (Bocken et al., 2019, p. 1501).

2.2.2. Tools within the early-stage SBMI process and their incorporation of sustainability considerations

The process of SBMI is iterative, but can be seen as consisting of different stages, such as idea generation, concept development, experimentation, piloting, and, finally, implementation (Geissdoerfer et al., 2017), with different tools existing for these stages.

In the early stages of SBMI, so-called 'strategies' or 'patterns' give practitioners inspiration on the wide range of possible SBM innovations. Examples of strategies include the provision of functions or experiences instead of products, such as leasing models, buy-back schemes or repair services for lifetime extension. Such strategies are often utilized in card decks, such as the Circularity Deck (Konietzko et al., 2020), the Sustainability Innovation Pack (Breuer and Lüdeke-Freund, 2018) and CE BM Pattern Cards (CircIt Nord, 2020), or into models such as the Circular Strategy Scanner (Blomsma et al., 2019). Most of these tools assume that environmental and/or social impacts can be reduced by implementing such strategies. Tools like these focus on idea generation and concept development, and are not specifically intended for nudging firms to critically consider the potential sustainability impact of these innovations.

However, tools also exist in which the user is asked to think about sustainability impacts on a more abstract level. In the Sustainable Value Analysis Tool (Yang et al., 2017), a box on environmental value prompts the users to consider the generated impact of the innovation in question. However, environmental and social impacts are often merely considered as broad types of "value", which the business model creates, alongside economic value. Similarly, The Cambridge Value Mapping Tool (Bocken et al., 2013) allows the user to place post-it notes into the fields "value captured", "value destroyed", and "value opportunities".

Explicitly highlighting the need of considering environmental and social impacts is popular in various sustainability-targeted extensions and adaptations of the business model canvas (Cardeal et al., 2020). These have a traditional, component-based, view on business models and either add new elements or layers to encourage the consideration of the social and environmental dimensions of sustainability (Antikainen and Valkokari, 2016; Daou et al., 2020; Joyce and Paquin, 2016), add new guiding questions (Fichter and Tiemann, 2015), or effectively restructure the canvas to place business model components within a social and environmental frame (Jones and Upward, 2014). Other tools rely on rules of thumb to prioritize between different strategies for innovation. Such tools tend to view strategies in relation to each other, for example those based on the waste hierarchy, such as the Circular Value Hill (Achterberg et al., 2016). Another example is the Ellen McArthur Foundation's butterfly diagram (EMF, 2013), which visualizes the cycling of technical and organic resources, and where the general rule of thumb is to aim to close the resource loops closest to the middle of the diagram.

The tools discussed do not include instructions to explicitly estimate sustainability impacts. However, Bhatnagar et al. (2022) outline the role of designated sustainability assessments within the SBM innovation process. To foresee impacts of activities, Bhatnagar et al. (2022) summarize that sustainability assessments contribute to a better understanding of sustainability impacts and make these tangible for different stakeholders while highlighting the most pressing sustainability issues in an industry or focal firm. Furthermore, they contribute to a common language between internal and external stakeholders and create support for and accountability for decision making. As a central element for tool design, Bhatnagar et al. (2022) highlight a systems perspective.

3. Methodology

The three central principles of the Systems Thinking concept described in the state of the art (section 2) formed the groundwork for the analysis. Fig. 1 visualizes the application of ST principles into the further analysis and the interconnection between relevant sections of this article. The study underlying this article consists of the following phases: 1) developing the state of the art, which informs the further phase 2) conducting the analysis, and phase 3) presenting the results.

In the following sections, the methodology for conducting the analysis (phase 2) is described. Each step in the analysis was driven by a guiding question. A case is chosen to exemplify the translation of ST principles to SBM practice.

3.1. Translating the principles of systems thinking to SBMI practice through a case

> Guiding question: Which concrete elements can Systems Thinking principles be broken down to, which innovators then can identify with the purpose of early SBM sustainability assessment?

As visualized in Fig. 2, concepts are useful for understanding the world, but less applicable when wanting to act on the world. More general or abstract theories represented in concepts may be bridged to a contextual practice using principles. Compared to practice, principles are more general and less contextual – and thus leave room for interpretation (Skaar et al., 2020). Thus, to apply Systems Thinking to the real world, we need to translate its principles to concrete methods which can be used in practice.

The levels and assessment measures presented by Stave and Hopper (2007) presented the point of departure for translating ST principles to elements that need to be identified by SBM innovators for assessing sustainability at an early stage. We arrive at elements that help with the understanding of each of the three principles (e.g. "identify non-linear relationships" is one element of the principle "causal relationships & feedback mechanisms"). Moreover, a hypothetical case is used to show how the identification of these elements assists with sustainability assessment in SBM practice. Appendix A provides more details on the

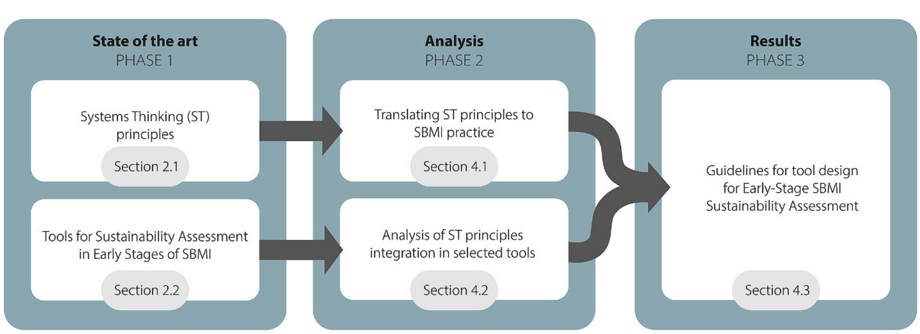

Fig. 1. Phases of analysis.

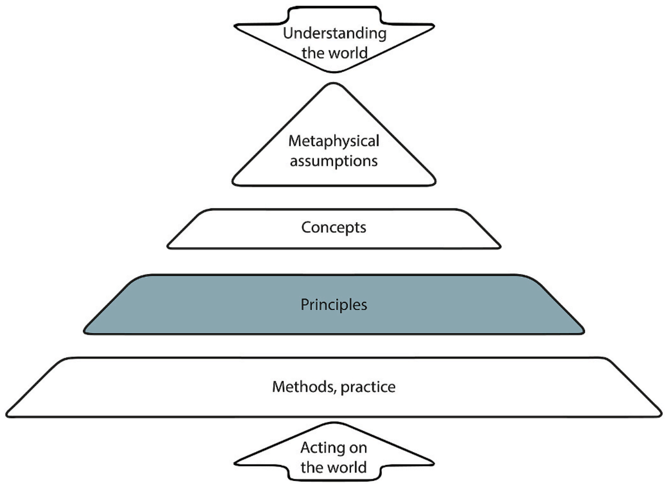

Fig. 2. The relationship between theory, principles, and practice. This illustration is based on a similar figure by Koskela and Kagioglou (2005, p. 44).

elements whose identification should be encouraged, in our case through the use of tools. A summary of the elements to be identified is presented in section 4.1.

3.2. Analysing the integration of systems thinking principles in selected tools

Guiding question: Which tools used for sustainability assessment in the early stages of SBMI include a Systems Thinking perspective? How do these incorporate the ST principles?

After exploring the landscape of tools in the early stages of SBMI in the State of the Art, we searched for tools used for early-stage sustainability assessment with a ST perspective. Our search took departure in the literature reviews by Bhatnagar et al. (2022) and Pieroni et al. (2019). For selecting tools for further analysis, a key criterion was that the tool is *appropriate for early stages of the SBMI process (a),* meaning that it should be possible to use the tool in a situation, in which several potential SBM innovations are considered, in which quantitative data might not be attainable, and in which time and professional competencies for an in-depth analysis are limited. The second criterion was the *integration of Systems Thinking (b)* in the tool. Only tools whose developers claimed to have integrated ST theory, or in which categories or descriptions of the tool itself refer to ST terminology were selected. Lastly, the *access to information on their development and intended use (c)* was important for our analysis. Thus, our selection has been limited to tools introduced in academic journal or conference articles in English language. As a result of this process, three tools have been selected for further analysis. It was analysed how exactly the tools encourage and help the user with identifying the elements of ST principles that were developed in 4.1. In an iterative process, contextual and methodological design characteristics identified during the analysis were added inductively to the initial ideas for guidelines for tool design that resulted from section 4.1. In this process, an important element was investigating how the tools reduce the complexity of ST principles. Key findings are presented in section 4.2.

3.3. Guidelines for the application of ST principles in SBM innovation impact tools

Guiding question: Which guidelines can assist tool designers with making practitioners use the three ST principles in their sustainability assessment in early SBMI stages?

Based on the previous analytical work, guidelines for integrating ST into sustainability assessment tools for the early stages of the SBMI process are presented. Structurally, the development of guidelines is inspired by the design theory for visual inquiry tools by Avdiji et al. (2020) and framework for environmental assessment developed by Baumann and Cowell (1999).

4. Analysis: Developing guidelines for integrating systems thinking principles into tools for early SBMI sustainability assessment

4.1. Translating System Thinking principles to elements for SBMI sustainability assessment

"Some [proponents of Systems Thinking] may dream of a society proficient in computer modelling of complex systems" (Plate and Monroe, 2014, p. 3), but in comparison to time-intensive Systems Dynamics practice conducted by the *"privileged and the few"*, Systems Thinking can build capacity for creating systemic insight for a greater number of people (Richmond, 1994). ST can be regarded as a subset of critical thinking skills, as *"synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviors, and devising modifications to them in order to produce desired effects"* (Arnold and Wade, 2015, p. 675).

In the following, we give an outline of which ST elements should be identified when assessing sustainability in the early stages of SBMI.

A **case** is used to exemplify the elements. We view a hypothetical dairy farm as a case who attended an event organized by a local agriculture network. At the event, the owner was approached by an employee of the local municipality. Together with the project employee, the dairy farmer currently considers investing in an anaerobic digester for converting the manure from their cattle into biogas. This biogas could serve as a power source on the farm but could also be sold to the local utility. In the following, each section showcases how a consideration of the three ST principles can support the partners involved in the SBMI while considering the overall impact of the innovation.

4.1.1. Interconnections

"The base level of thinking systemically is recognizing that systems exist and are composed of interconnected parts. This includes the ability to identify parts, wholes, and the emergent properties of a whole system. [...] Recognizing interconnections requires seeing the whole system and understanding how the parts of the system relate to the whole" (Hopper and Stave, 2008).

Grounding SBM innovation in ST requires a company being seen as an open system with a multitude of parts (from employees to suppliers and other external actors), where specific properties work together for a higher purpose (Boons and Bocken, 2018; Tsujimoto et al., 2015). We argue that the perspective can provide a lens to explicitly consider systems besides technological and economic ones and thereby enable a wider and more inclusive assessment of so-called *sustainable* business models. The interdependency between the parts inherent to SBMs is due to both the activities in the company itself, and activities with and by its suppliers, customers, and other external actors.

In the context of SBM, this also means recognizing that the business model can only be sustainable when the entire system, which it is part of, is sustainable (Jennings and Zandbergen, 1995), as "*changes to the socioeconomic system, both structural [...] and cultural [...] are required to facilitate firm-level [...] sustainability"* (Stubbs and Cocklin, 2008).

In our case, the previous business model consists of employees, customers, suppliers, and a logistics company that the farmer pays to discard manure. External systems that the business model is a subsystem of include the food systems, the labour market, and the local community. Through the SBM innovation, the farmer might identify the municipality, which buys generated biogas, as a new customer and thereby a new part of the business model. The energy system, which this biogas is delivered to, presents a new wider system that the new business model becomes a subsystem of.

In the context of SBMI, stocks and flows are of importance as well. A company's inventory as well as materials on the global resource market are stocks, while production, which increases the inventory, but decreases the availability of a material on the global resource market are flows. It is necessary to distinguish levels (integrations or stocks) from rates (flows or activity) before moving on to identifying causal relationships between them (Forrester, 1994).

4.1.2. Causal relationships & feedback loops

Once relevant subsystems, systems, and their constituent parts have been identified, *"the ability to identify cause-effect relationships between parts of a system [and to] describe chains of causal relationships"* is required (Hopper and Stave, 2008, p. 5). This is where interrelated thinking is of importance, taking into account indirect effects and networks of causes and effects (Ossimitz, 2000).

The relationships occur within and across systems boundaries. For example, a change in material may impact product design and production processes, while access to a certain material on the global market may be affected by shifts in national policy or other landscape events (e.g., armed conflicts, pandemics). Currently, there is increasing concern that those *"crucial interconnections with the macro level"* are being ignored (Pla-Julián and Guevara, 2019, p. 74) due to a *"management and technocentric bias driving the circular economy agenda"* (Corvellec et al., 2022, p. 427). Corvellec and colleagues (2022, p. 428) state that failure to recognize these connections can result in labour practices, working conditions, power asymmetries, political and economic constraints, and issues of equity and inclusion being overlooked. Considering a myriad of relationships between the business model and its surroundings are central for understanding and assessing the interdependency between actors (the company and other stakeholders), in different sustainability domains (climate change, biodiversity, economy etc.) and at different scales (within the company, local, national, and global), and ultimately help secure a systems perspective.

Looking at the wider production and consumption systems, sustainable business model innovators have to recognize that even the most sustainable product or service is not sustainable if there is no need for it or if the consumption systems could be designed differently to fulfil the need. Defining the question of need and sufficiency in the consumption system is probably the most important and challenging dimension on the journey towards a sustainable future in the context of sustainable business model innovation.

In our case, the partners might ask themselves which causal relationships can be identified between the system's parts. The local community might benefit if the handling of manure is improved in a way that it leads to a reduction of smell. The energy system can benefit from an addition of biogas: The generated biogas is used a power source on the farm, the rest is sold to the local utility. The impact is that less coal or investment in alternative energy is needed.

Besides identified causal relations and chains, it is also necessary to recognize that closed causal chains create feedback (Hopper and Stave, 2008). Individual transactions, which might seem to be small, random events, can accumulate and become magnified by positive feedbacks (Arthur, 1994). According to Nooteboom (2007), the feedback resulting from interaction between system elements can play a key role in assessing the impacts of a plan, initiative, or of a larger system. In our example, an accumulation of investments in anaerobic digesters could lead to a dependence of the municipality on factory farms to source their energy, which in turn positively influences the ownership of anaerobic digesters. This is an example of how a feedback loop is reinforcing the system to continue in a specific direction and makes the system rigid and difficult to change (cf. 'lock-in' (Seto et al., 2016)). The contribution to undesired feedback loops might represent an unexpected effect of this specific SBMI.

ST also always has a pragmatic component, as *"it deals not just with contemplating the system, it also is interested in system-oriented action"* (Ossimitz, 2000), the practical steering of systems. After recognizing that system-level unsustainability hinders the sustainability of the business model, leverage points for changing the system towards a more sustainable direction have to be identified. The accelerating positive feedback loops that might lead to system destruction can be cancelled or reduced by adding negative feedback (Zeigler et al., 2000). Negative feedback loops, which are contributing to maintaining a status quo, might also reveal points for leverage in locked-in systems.

4.1.3. System change & adaptations

An ability of ST is to see patterns of change rather than static snapshots (Senge, 1990), taking into account evolution over time, and the thinking in dynamic processes (e.g. delays, oscillations) (Ossimitz, 2000). It also means foreseeing possible future developments, as this is needed for the practical steering of systems (Ossimitz, 2000). The identification of feedback loops can help predict the future through extrapolation (Nooteboom, 2007).

For assessing sustainability of SBMI, this means that there is a need to assess the business model in the light of general surrounding system changes (Løkke and Madsen, 2022). This is essential in early-stage SBMI processes and can also be enabled using insights from consequential life cycle assessment (LCA) modelling. The adaptation element is central to considering the relationships between the SBM and its surrounding systems (actors, sustainability domains, and scales) across time (now and future). Companies applying a system perspective will need to revisit their SBM continuously during development and implementation in order to adapt to the reality of system changes, both internally as well as externally to the company. Groeger et al. (2019) call this a need for *"ongoing responsive change in the business model"* (p. 110). As the company as a system together with its surrounding systems change, so will the sustainability of its SBM.

Not only predicting, but also imagining future (desired) states of the system in the context of SBMI may be useful for understanding the sustainability of the SBM. This could include imagining a true circular economy, in which no resource is considered waste, and all resources are equally important. If a resource is currently considered to be 'saved from being wasted', e.g. by being recycled or reused through an SBM, when is this situation likely to change? This question helps considering how limited the supply of the resource is and which alternative uses might be relevant or even competing with the current use of the resource in the future.

In our case, the partners involved in the SBMI might consider which changes in surrounding systems could impact the sustainability of this business model in the future. They might consider other potential business model innovations that can be realized simultaneously or consecutively. The farmer could consider that they will source new kinds of feed, which have lower environmental impact, either by reducing methane that the cow emits or by the feed production itself using less land or transport. The consequence would be a change in the properties of the waste. To adapt to this change, the farmer will have to investigate if this influences the anaerobic digestion. The farmer could also recognize that customer preferences or agricultural policies might change, resulting in less demand for dairy products or fewer subsidies for dairy farmers. The consequence would be that the farmer might have to reduce their dairy production. To adapt to this change, sourcing of alternative biomass for our anaerobic digestors would have to be considered.

Fig. 3 summarizes the ST elements needed for sustainability assessment in the early stages of SBMI. Appendix A outlines details on these.

4.2. Application of systems thinking principles in early-stage SBMI sustainability assessment

Different demands for sustainability assessment tools during the SBMI process are reflected in the matrix presented in Fig. 4.

In early stages of SBM innovation process, uncertainty is high and

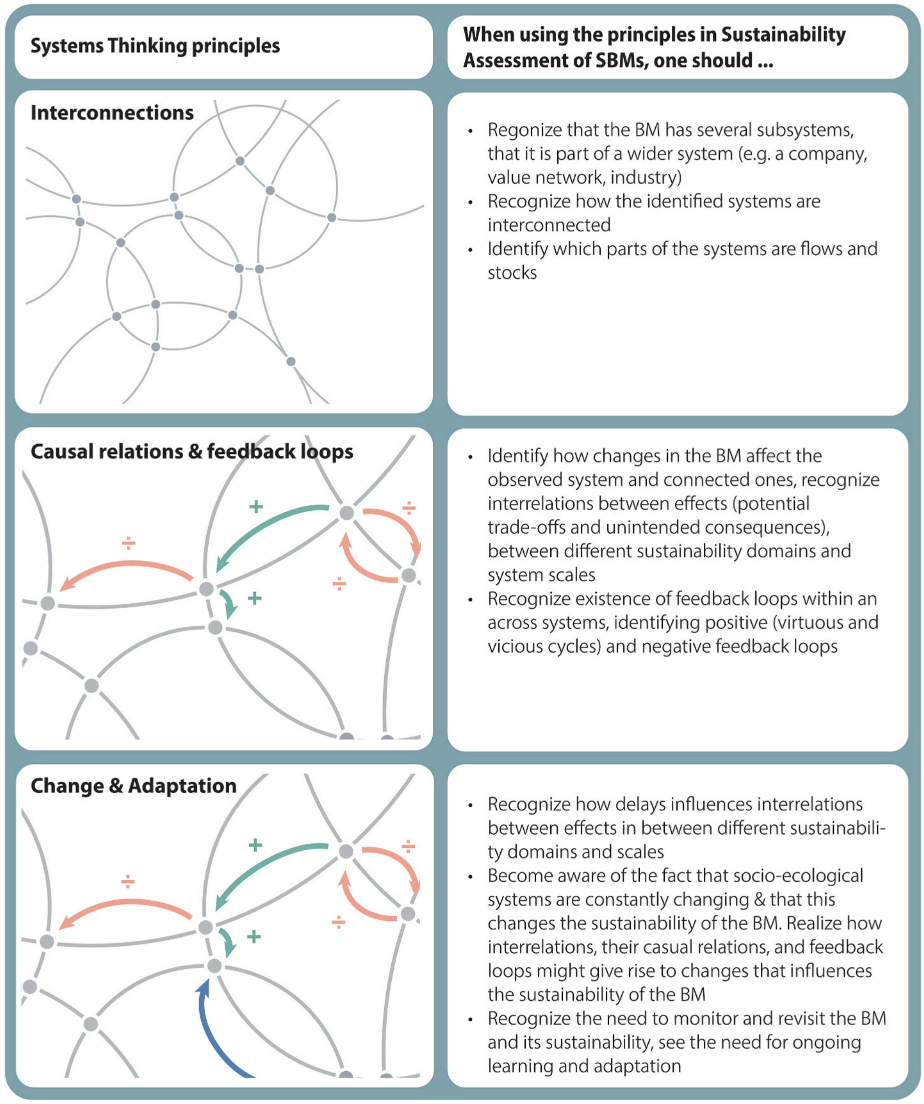

Fig. 3. Applying Systems Thinking principles for early-stage sustainability assessment in the sustainable business model innovation process (see appendix A for details).

there is a lack of data but, at the same time, it is the stage in the process in which it is possible to redirect the focus of the innovation (Matthews et al., 2019). In latter stages of the process, the sustainability can be assessed with high detail, looking back on the previous activities (ex-post, retrospective), while in early stages, the purpose of the tools is to predict effects (ex-ante, prospective assessment) (Baumann and Cowell, 1999; Bhatnagar et al., 2022). Bocken et al. (2012) argue that LCA modelling belongs to the later SBMI stages. This primarily refer to 'backwards-looking' accounting style LCA. Decision oriented consequential LCA can, however, play a very important role in earlier SBMI stages as the modelling enables an improved understanding of the context and interconnectedness of the SBM under innovation, and of how design decisions interact with the surrounding system. An important element is the quantification or rather projection of how SBMs prospectively will interact with the surrounding system. In Fig. 4 we call this "screening LCA, business model LCA".

Especially tools of visual enquiry are relevant to the early stage of the SBMI process, as they frame a strategic management problem with a conceptual model and relevant components, create a shared visualization by structuring the components logically into a visual problem space, and do not require an inappropriate amount of time or other resources (Avdiji et al., 2020). Examples include practitioner tools such as the impact canvas by Gerlach (2015) or the general sustainability qualifying criteria developed by Pieroni et al. (2018).

A handful of these tools also explicitly incorporate a ST perspective. These tools that already do so are the rapid circularity assessment (RCA) (Bocken et al., 2016), the GAIA model (Kørnøv et al., 2020; Schlüter et al., 2022) and the trade-off navigation framework (Kravchenko et al., 2021). In Fig. 4, these are visualized as green circles and located on the SBMI-process diagonal.

We analysed how the three selected tools used for sustainability assessment in early-stage SBMI encourage the identification of ST elements outlined in Fig. 3. The systematic analysis is presented appendix B and summarized in the following.

In terms of **format**, all tools lead the user through a clearly defined process of steps. The RCA and the TONF provide an assisted use of the tool by asking closed questions and by requiring a sequence of excel cells to be filled out. The GAIA tool poses more open-ended questions and thereby provides less guidance, but also more room for additional considerations depending on the user's knowledge.

The tools differ in their **purpose and scope of application**. The RCA model is especially relevant for SBM innovations that reuse or recycle

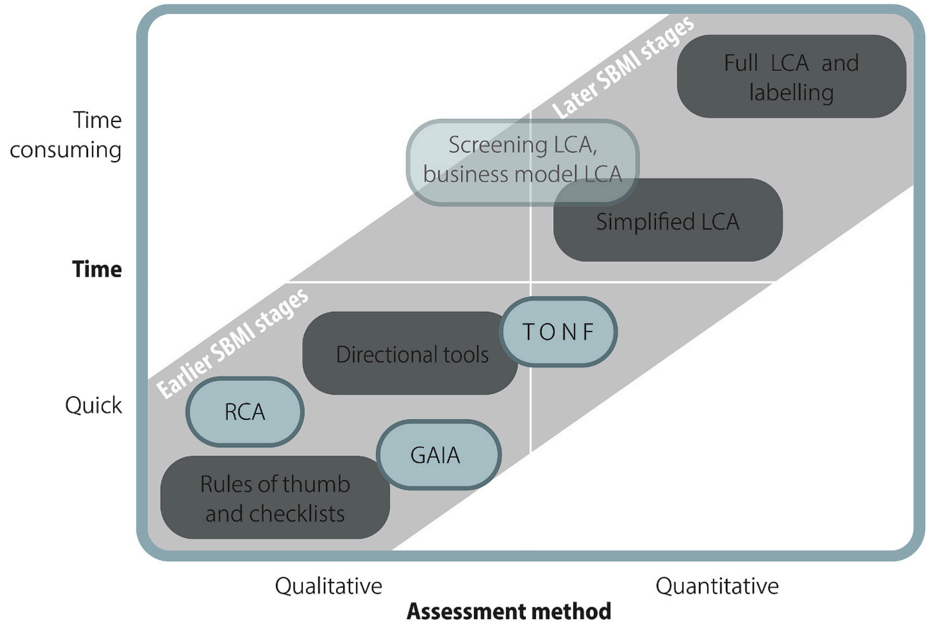

Fig. 4. *Location of the three selected tools within a classification of sustainability assessment tools, adapted from* Bocken et al. (2012).

resources and extend product lifespans: the GAIA model for innovations in which a change of resource inputs or application of output resources occurs, and the TON-framework for product innovations. The fact that these tools have a focal application suggests that tools incorporating ST principles might benefit from a well-defined and narrow scope of application.

Collaboration plays a varying role in the tools analysed. GAIA is to be used by different companies in the envisioned sustainable business model and thereby reflects the different partners' wider system impacts, while RCA does not explicitly encourage co-creation. In contrast, the main ambition of TONF is to encourage discussions and negotiations, on which its success depends.

The tools differ in terms of which number, kinds, scales, and **interconnections** of systems the user is encouraged to consider. Firm- and even product-level *subsystems* are the core focus in the TONF model as it focusses on product design criteria. The GAIA incorporates several SBM-internal elements relating to the design, process, and application of resources across collaborating organizations. RCA points towards stores and employees as an SBM-internal element. In terms of *surrounding systems*, RCA and GAIA show how limited considerations of wider system impacts are possible, especially for unintended impacts.

The tools include aspects of the second ST principle, **causal relations**, to a large extent, urging the user to consider various kinds of intended and unintended impacts in systems of different types and scales. **Feedback loops** are not included to the same extent. Only the RCA tool asks one question that could point into the direction of feedback loops. In the GAIA model and TON-framework, feedbacks loops might be identified in the processes that urge users to consider unintended consequences across systems, but their consideration is not explicitly encouraged.

System changes and adaptation is a principle much less reflected in the analysed tools, with the temporal dimension of change not explicitly being highlighted. It is only the need for revisiting and adapting the model which receives some attention, even though it is not incorporated in the tool design but limited to the instructions on how the tool is used. In the GAIA model, this need is described as a general principle, while TONF states in its instructions that acceptable ranges and targets are flexible and to be adjusted along the decision-making process.

Moreover, the tools differ in terms of which **sustainability dimensions** are included. For example, the GAIA model leaves this decision up to the user while the RCA does the same but suggests "waste" as an example of an impact category. Lastly, the TONF incorporates goals and limits set by the user, rather than specifically defined impacts. In terms of **flexibility of integration** and **compatibility with other tools**, the RCA draws a connection to the circularity strategies framework of closing and slowing resources loops, while the GAIA model recognizes the integration with LCA as another sustainability assessment tool in the SBMI process.

4.3. Guidelines for integrating systems thinking in early-stage SBMI sustainability assessment

Based on translating Systems Thinking principles to SBM practice and analysing selected tools for early-stage SBM sustainability assessment, a series of guidelines for future tool design are developed and presented.

Forrester (2010) voiced the concern that *"without a foundation of systems principles, simulation, and an experimental approach, Systems Thinking runs the risk of being superficial, ineffective, and prone to arriving at counterproductive conclusions"*. In quick and qualitative tools for sustainability assessment in the early stages of SBMI, this problematic is inherent. Using ST in practitioner tools thus requires that we too consider a trade-off: We can either acknowledge systems complexity and create tools that are difficult to use without insight into a breadth of systems dynamics, or choose a limited selection of systems relations that we want practitioners to consider during the SBM innovation process. Arnold and Wade (2015) argue that an intuitive simplification is part of ST. The analysed tools enable a look at systems in ways that reduces excess and complexity.

Just as passengers travelling by subway do not need to comprehend all technical information regarding the subway systems design or

Table 1
Guidelines for integrating Systems Thinking in early SBMI sustainability assessment.

#	Guideline
1	Define scope of application
2	Design for collaboration
3	Integrate principle “Interconnections”
4	Integrate principle “Causal relations & feedback loops”
5	Integrate principle “System change & adaptation”
6	Consider sustainability dimensions
7	Ensure flexibility of integration
8	Ensure compatibility with other assessment tools

The guidelines are presented in the following text.

operation to know how to get from A to B (Wade and Heydari, 2014), firms innovating their business models for sustainability do not need to know every detail on the workings of the global economy to get a grasp of the SBM’s sustainability impacts at an early stage of the innovation process. Tools can enable SBM innovators to identify the most relevant systems parts, interconnections, and leverage points.

In the following, we outline suggestions on how this balancing act can be performed in tool design through the following eight core design guidelines. These guidelines are summarized in Table 1. The guidelines encompass contextual (#1–2, #7–8) as well as methodological considerations (#3–6).

Guideline 1: Define scope of application

One main suggestion for incorporating ST principles into tools is to design the tool for a specific use (e.g., product design) or context (e.g., fashion industry). This enables a more streamlined and focussed consideration of the following methodological factors.

Guideline 2: Design for collaboration

Designing for collaboration is critical to allow the user to identify the most relevant systems and causal relations, as more actors know more about different systems, their interconnections, and relations. This can be done by explicitly encouraging the use of the tool in a collaborative setting and by defining the roles of different partners in the use of the tool. An example of how collaboration is incorporated in tool design is presented by the GAIA model, which explicitly encourages the model to be filled out from the perspectives of partners collaborating in SBMI.

Guideline 3: Integrate principle “interconnections”

Tools can support the user with identifying systems and with taking into consideration and recognizing their interconnectedness. To do so, the tool design should be supportive in identifying an appropriate amount and scope of systems, both internal and external to the business model. A tool designer should consider nudging the user to reflect on those systems that are usually neglected or shown to hold unexpected impacts, within the scope of application of the tool (e.g., product design, a certain industry).

The temporal dimension of impacts has been neglected in the analyzed tools, and to recognize delays in effects leading to future systems changes (see guideline 5) it can be helpful to enable the user to differentiate between stocks and flows. This can be supported in the tool design by using analogies for stocks and flows with phenomena that have surface similarity, as humans have limitations in seeing common behavioural characteristics if the phenomena differ in their surface characteristics (Gonzalez and Wong, 2012). Another example of instructions that can help is to ask the user to consider what would happen in the system if time were to stop, and explaining that stocks, would continue to exist, while flows would disappear.

Guideline 4: Integrate principle “causal relations & feedback loops”

A focus can be on causal relations that have been found to be problematic in practice. The analysed tools show such an approach well by focusing on known trade-offs as in the TONF tool or commonly disregarded systems consequences of actions as incorporated in the RCA and GAIA tool. The identification of feedback loops is currently neglected in tools, but could be encouraged through a problem-based approach, in which users are encouraged to consider why a system is locked in and which feedback loops provide opportunities for leveraging and breaking these lock-ins.

Guideline 5: Integrate principle “system change & adaptations”

The analysed tools only incorporate this principle to a minor extent. One way to start incorporating this principle is to use the stocks and flow notion and prompting the user to consider delays based on it. Another is to prioritize the identification of positive feedback loops and consecutively encourage the user to extrapolate them to predict future systems changes. Alternatively, open-ended or direct questions might enable the user to consider future development and needed adaptations.

Guideline 6: Consider sustainability dimensions

Even though sustainability depends on a complex and difficult to grasp combination of network relations, in practice this realization leads to very broad frameworks and simplified models that e.g., stays within economy-society-environment silos and that do not make it easier for practitioners to identify network relations. Naming more detailed impact dimensions or outlining exemplary network relations within these broader categories can give the tool user more guidance than simply referring to these very broad silos of impacts.

Guideline 7: Ensure flexibility of integration

One tool cannot cover all the aspects of designing a SBM. Integrations or synergies between the tools for sustainability assessment and tools that cover other aspects of SBMI should be anticipated (Avdiji et al., 2020). Is it consecutive, complementary, competing, encompassing, or overlapping with other tools used in the early stages of SBMI (Baumann and Cowell, 1999)?

Guideline 8: Ensure compatibility with other assessment tools

How is the relationship of this tool with other tools used in SBM sustainability assessment? Is it consecutive, complementary, competing, encompassing, or overlapping with other tools for sustainability assessment of SBMI?

A logical next step, once the principles have been considered, is consequential life cycle assessment, which is shown to align with ST principles. Both the consequential LCA-system modelling approach and general ST theory share the view of seeing virtually any thinkable activity as embedded in interlinked and nested open systems (Onat et al.,

2017) of network relations, characterised by communication and the impossibility of isolated change. In order to understand the interconnectedness of SBM, Life Cycle Assessment can as a science-based tool support the quantification of impacts of SBMs through their life cycles and can be a critical support for achieving sustainability. Consequential LCA can show the consequences of different decisions made in the SBM innovation in question, can guide the optimisation of the context dependent SBM performance, and can further avoid system trade-offs (Løkke et al., 2020; Weidema et al., 2018, 2020).

5. Conclusions

This article took departure in a key challenge for practitioners involved in Sustainable Business Model (SBM) innovation: Ensuring that changes to a business activity lead to a positive change in the sustainability of the wider system and having easy-to-use tools available at an early stage in the innovation process, which enable a systemic view.

Translating Systems Thinking principles to elements to be identified within the Sustainable Business Model innovation process allowed us to outline how this can assist with assessing the innovation's sustainability at an early stage in the process. Previous recommendations for tool design have highlighted a systemic perspective as a central element for tool design, particularly to decide on the system boundaries of the assessment (Bhatnagar et al., 2022). Our analysis shows that considering Systems Thinking principles in the design of tools for sustainability assessment of SBMs can go beyond the definition of the scope of considered impacts. Using Systems Thinking principles can enable innovators to identify unintended impacts of an envisioned innovation, see how systems are or can become locked-in as a consequence of the innovation, and predict system changes that influence the sustainability of their innovation.

The analysis highlights that Systems Thinking can assist the sustainability assessment of SBMs and can be enabled through appropriate tool design. Eight design guidelines have been recommended.

1. Define scope of application
2. Design for collaboration
3. Integrate principle "Interconnections"
4. Integrate principle "Causal relations & feedback loops"
5. Integrate principle "System change & adaptation"
6. Consider sustainability dimensions
7. Ensure flexibility of integration
8. Ensure compatibility with other assessment tools

Effective design of tools does not only take into consideration contextual factors, such as the scope of application and the compatibility with a wider SBM toolbox, but also methodological factors. These methodology factors should aim at enabling the identification of elements of three crucial ST principles: Interconnectedness, Causal relations & Feedback loops, and System change & Adaptation. Balancing an effective understanding of ST principles while at the same time reducing complexity is a main challenge in this regard. Complexity is reduced through several methods. One method is presenting a clear frame, in which some systems are selected for closer consideration beforehand (e.g. suppliers, customers).

The tools can act as a mirror for the business analyst, extending insights into how the causal relationships characterising the physical reality of activities and market conditions shape the society-wide impact of activities, and thereby enables the transgression of preconceived perceptions of what constitutes 'green' or 'sustainable' business models. We also showed that the System Thinking perspective holds important information for designing the assessment of lifecycle impacts throughout the SBMI process. As such, the three analysed tools provide a bridge between the 'business model world' and the 'environmental system modelling world'.

Ultimately, Systems Thinking principles can help to close the gap between theory and practice and provide a common language and an accessible framework for relevant stakeholders to engage with in a domain that otherwise may seem inaccessible. This facilitates a more focused effort from SBM practitioners, ensuring that sufficiently detailed modelling is used for decision-support and to test the validity and sustainability of proposed SBMs.

By providing guidelines for the integration of Systems Thinking principles in tools for early SBMI sustainability assessment, we operationalized an abstract Systems Thinking concept and showed how it can facilitate change. Thereby, we not only contributed to the study of sustainability assessment for SBMs, but also to the field of Systems Thinking and its application.

Our study entails implications for future research. One is the analysis of compatibility between existing tools within and across stages of the SBMI process. Another is the exploration of alternative tools than visual inquiry tools. Even though none could be identified in literature, it is imaginable that tools could take the shape of games, as games for re-engineering business processes based on Systems Thinking have been developed successfully in other contexts (see e.g. Van Ackere et al., 1993). Lastly, a research avenue to be considered relates to further exploration of the effectiveness of visual inquiry tools to support Systems Thinking for sustainability assessment. While we outlined general design guidelines in this research based on an analysis of existing tools, applying selected tools on cases of sustainable business model innovation and conducting comparative or longitudinal studies on their use within these processes holds potential. This could lead to important insights on how decision-makers interact with these tools and which design criteria prove most relevant in supporting Systems Thinking for sustainability assessment.

CRediT authorship contribution statement

Leonie Schlüter: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. **Lone Kørnøv:** Conceptualization, Methodology, Writing – original draft, Supervision. **Lucia Mortensen:** Conceptualization, Methodology, Writing – original draft. **Søren Løkke:** Conceptualization, Methodology, Writing – original draft. **Kasper Storrs:** Conceptualization, Writing – review & editing. **Ivar Lyhne:** Conceptualization. **Belinda Nors:** Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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Appendix A. Elements of applying Systems Thinking Principles in Early-Stage SBM Sustainability Assessment

	The tool should encourage the user to identify …
Interconnections	**Subsystems** *Recognize the subsystems within the BM (e.g. production processes, employees, suppliers) and see the BM in its entirety* - Number of subsystems considered - Scope (how detailed?) **Surrounding systems** *Recognize that the BM is part of wider systems (e.g. a company, value network, industry)* - Number of wider systems considered - Scope (how close to the SBM system?) **Connections between the parts** *Recognize how the identified systems are interconnected (e.g. relation between BM system and consumption systems, labour practices, other BMs in the same company, other industries)* **Stocks and flows** *Identify which parts of the systems are flows (inflows or outflows, measured over a certain interval of time) and stocks (entity that is accumulated over time by inflows and/or depleted by outflows)*
Casual relationships & feedback loops	**Causal relations** *Identify how changes in the BM affect the observed system and connected ones, recognize interrelations between effects (potential trade-offs and unintended consequences), between different sustainability domains and system scales.* - Linear - Non-Linear - Chains and networks **Feedback loops** *Recognize existence of feedback loops within an across systems, identifying positive (virtuous and vicious cycles) and negative feedback loops.* - Negative feedback loops - Positive feedback loops
System change & Adaptation	**Dynamic behaviour & delays across system elements impacts** *Recognize how delays influences interrelations between effects in between different sustainability domains and scales* **Future developments** *Become aware of the fact that socio-ecological systems are constantly changing & that this changes the sustainability of the BM. Realize how interrelations, their casual relations, and feedback loops might give rise to changes that influences the sustainability of the BM.* - Scope (how close to the SBM system?) - Time frame (how far away in the future?) - Likelihood (imaging easily predictable outcomes or utopic states) **Need for ongoing learning, monitoring, and adaptation** *Recognize the need to monitor and revisit the BM and its sustainability, see the need for ongoing learning and adaptation to deal with this high complexity and challenging predictability*

Appendix B. Analysis of how the three selected tools incorporate and operationalize Systems Thinking principles

The tool should encourage the user to identify …		RCA	GAIA	TONF
Interconnections	**Subsystems**	Example for subsystem is given: “stores and employees”	Four systems within BM: Design changes, process changes, previous, and future application of resource	Focusses on subsystems of the innovation, namely on product properties. Criteria can be chosen by the user, but examples are given: Recyclability, Lifetime, Cost of materials, Energy use for production, Local supply of materials, Eco-labelled materials, Material Circularity Indicator
	Surrounding systems	Example for surrounding systems are given: “wider system”, “society”	By making the user compare previous and future application of a resource, it encourages to consider the wider resource markets that the internal use of a resource influences.	Choice of criteria determines the consideration of surrounding systems: Recyclability includes the recycling market as an external system, energy use for production the energy sector.
	Connections between the parts	Encourages the user to think about the impact of the innovation on the above-mentioned examples and beyond, thereby implying a connection between the systems.	Encourages the user to consider how a change in resource use impacts the design and processes of their product/service.	Discussions in how far the criteria reflect connections between systems and their parts is left to the users. The tool encourages discussions by making users define negotiable and non-negotiable criteria, acceptable ranges and limits, and, finally, showing trade-offs between criteria.
	Stocks and flows	Stocks-and-flows notion is a structural element of tool: Sold products as flows, existing clothing as stock	–	–
Casual relationships & feedback loops	**Causal relations**	Examples of undesired properties of larger systems (trends of clothing overconsumption), unintended consequences (where textiles are used as a low-cost filler what is likely replacement if we can	The GAIA framework requires the user to consider the reused or recycled resource, substituted resource, required changes in the processing of the resource and/or in product design, as well as the former use of the resource. It thereby offers the possibility to reveal unexpected systematic impacts.	Only relations between importance of criteria and resulting trade-offs.

(*continued on next page*)

(*continued*)

The tool should encourage the user to identify …		RCA	GAIA	TONF
		divert textile waste?)", positive unexpected impacts (from fast to slow fashion). Potential rebound effects mentioned as one of the systems effects and an example is given for an undesired rebound effect "(consuming more)".		
	Feedback loops	Asks about the effect of multiple co-existing business models and thereby points to the fact that some impacts, such as lock-ins caused by positive feedback loops, might only become apparent when BMs are applied in a critical mass	–	–
System change & Adaptation	**Dynamic behaviour & delays across system elements impacts**	Delays of decision impacts are not explicitly highlighted, and their consideration depends on the user's ability to judge the impact of a resource changes across the identified systems.	Delays of decision impacts are not explicitly highlighted, and their consideration depends on the user's ability to judge the impact of a resource changes across the identified systems.	Temporal dimension is not explicitly considered, but implicit in the setting of goals for certain criteria.
	Future developments	Predicting future developments is not explicitly encouraged and depends on the user's knowledge of developments in the considered systems.	Predicting future developments is not explicitly encouraged and depends on the user's knowledge of developments in the considered systems.	Temporal dimension is not explicitly considered, but implicit in the setting of goals for certain criteria.
	Need for ongoing learning, monitoring, and adaptation	Not explicitly highlighted	Need for revisiting and continuously adapting the SBM due to internal and external changes is put forward as a general principle.	Prompts user to choose negotiable criteria, where acceptable ranges and targets are flexible to be adjusted along the decision-making process. The acceptability ranges encourage negotiations with internal or external stakeholders and managers.

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