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Article

Tools and Frameworks for Sustainable Business Model Innovation in the Hydrogen Context for German Steel, Cement, and Chemical Industries

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Abstract: In the decarbonization of the steel, cement, and chemical industry in Germany, green hydrogen is expected to play a crucial role. The utilization of green hydrogen in the production processes of said industries requires organizations to modify their business model, requiring sustainable business model innovation (SBMI). Numerous tools and frameworks that support organizations in the process of SBMI have been proposed in the literature in recent years. However, the applicability of these tools and frameworks for steel, cement, and chemical companies that intend to utilize green hydrogen to produce their goods remains unexplored. By conducting a systematic literature review on tools and frameworks for SBMI, a literature and practice review to identify and analyze existing green hydrogen projects of steel, cement, and chemical companies, and an evaluation of the identified tools and frameworks in an evaluation matrix, this paper aims to assess the suitability of SBMI tools and frameworks for steel, cement, and chemical companies that plan to use green hydrogen to produce their goods. Based on the evaluation, the Cambridge Business Model Innovation Process (CBMIP) was identified as the most suitable SBMI framework.

Keywords: sustainable business model innovation; decarbonization; sustainable business model; climate change; framework; energy-intensive industries

1. Introduction

In the face of escalating climate change concerns, nations worldwide are adopting more rigorous strategies to mitigate greenhouse gas (GHG) emissions. Among these efforts, Germany's ambitious goal to achieve climate neutrality by 2045, as outlined by the amendment to the Climate Change Act in 2021, is particularly noteworthy [1]. This legislative milestone underscores the urgency of addressing climate change and positions Germany at the forefront of global efforts to mitigate environmental degradation [2,3].

The steel, cement, and chemical industries are among the largest contributors to GHG emissions within the industrial sector, collectively responsible for approximately 55% of the industrial sector's emissions in Germany and 10% of the nation's total GHG emissions [4,5]. These industries are characterized by energy-intensive processes that are challenging to decarbonize due to their reliance on high heat and the resultant process emissions [5–7]. The decarbonization of these sectors is thus both a significant challenge and an essential component of achieving overall climate neutrality [8,9]. The challenge of decarbonizing these sectors is underscored by both technical and economic barriers, including reliance on high-heat processes and substantial process emissions of carbon dioxide, alongside issues like low profit margins, high capital requirements, and long asset lifetimes [9–11].

An economically attractive low-carbon transition, i.e. far-reaching emission reductions with constant sales volumes, requires a combination of process and product innovations as well as

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business model innovations. Over the last two decades, industry has made a significant contribution to reducing emissions. Nevertheless, further reductions are necessary and possible, but these are no longer quick wins [12]. Innovative business models have the potential to reduce emissions [12,13]. Business model innovation defines the change or redesign of the basic logic of how an organization creates, delivers and captures value [14–18]. In the quest to decarbonize the steel, cement, and chemical industries, SBMI plays a pivotal role, offering a fresh perspective on how organizations can create, deliver, and capture value with an eye towards substantially reducing negative environmental impacts [17,19].

Among the various ways proposed to achieve decarbonization, the utilization of green hydrogen presents a promising avenue [7,20]. Green hydrogen, produced through the electrolysis of water using electricity generated from renewable energy sources, offers a pathway to significantly reduce GHG emissions, particularly in energy-intensive industrial processes. This technology is not only viable for producing clean energy but also serves as a critical component in the transition towards a more sustainable industrial landscape. Demonstration projects across the steel, cement, and chemical industries have evidenced the technological feasibility and environmental benefits of integrating green hydrogen into production processes [6,21]. However, the transition to green hydrogen necessitates substantial changes in business models, particularly in the domains of value creation and delivery. This shift requires an in-depth understanding of the interplay between technological adoption and business strategy [22–24].

Despite the growing academic interest in SBMI, the literature remains nascent, especially concerning its application within the specific context of the steel, cement, and chemical industries [14–18]. There is a notable gap in understanding how these industries can leverage SBMI tools and frameworks to facilitate the transition towards using green hydrogen in production processes. This gap points to a critical area of inquiry, given the unique characteristics of these industries, including their capital-intensive nature, long asset lifetimes, and the integral role they play in the broader industrial ecosystem [11]. Therefore, this paper aims to navigate this uncharted territory by addressing the following research question: Which tools and frameworks for SBMI are suitable for companies in the steel, cement, and chemical industry that intend to use green hydrogen to produce their goods? This investigation intends to indirectly enhance the strategic dialogue concerning Germany's ambitions for climate neutrality. By assessing the relevance of SBMI tools and frameworks within this specific industrial framework, the study subtly supports the alignment of economic resilience and environmental stewardship in pivotal sectors, thereby aiding in the broader endeavor to address the challenges of climate change.

2. Materials and Methods

This study aims to analyze specific tools and frameworks for SBMI for their applicability to companies in the steel, cement and chemical industries, especially those that incorporate green hydrogen into their production processes. To achieve this, a multi-faceted methodology was employed, comprising a systematic literature review, an extensive practice and grey literature search, and the development of an evaluation matrix for assessing SBMI tools and frameworks.

Initially, a systematic literature review was conducted following the guidelines set by Moher et al. (2009), utilizing the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) flow diagram [25]. The literature review focused on sustainable business model (SBM) tools. This involved a meticulous search strategy using keyword combinations like "sustain* business model*" AND "tool*", "SBM" AND "tool*", and similar phrases. The search, executed on the Web of Science database on March 25, 2023, focused on titles, abstracts, and keywords. This process identified 28 relevant articles and 21 tools and frameworks pertinent to SBMI.

Due to the limited academic literature on green hydrogen projects in the steel, cement, and chemical industries, a combination of literature and practice review was essential. This approach, modeled after [25], aimed to gather insights into the practical application of green hydrogen by these industries. The review extended to several hydrogen project databases and grey literature, including company websites and news articles. Key resources explored were the hydrogen project map of the

Deutsche Energie-Agentur (dena), the European Clean Hydrogen Alliance's project pipeline, and the Hydrogen Projects Database of the International Energy Agency (IEA). These databases provided a comprehensive overview of existing hydrogen projects relevant to the target industries, with a particular focus on projects in Germany and across Europe.

Finally, an evaluation matrix was developed to assess the suitability of the identified SBMI tools and frameworks for companies in the target industries. This matrix was formulated using criteria derived from multiple sources, including general characteristics of companies in energy-intensive industries, challenges faced during SBMI, and insights from the analysis of existing green hydrogen projects. The matrix served as a tool to systematically evaluate each SBMI framework and tool in the context of its potential application in the steel, cement, and chemical industries using green hydrogen.

Through this methodology, the study aimed to fill the knowledge gap regarding the applicability of SBMI tools and frameworks for industries transitioning to sustainable practices, specifically those incorporating green hydrogen in their production processes.

3. Results

This chapter commences with the introduction of SBMI tools and frameworks that were identified through the systematic literature review. Afterwards, the evaluation criteria, that were derived from multiple sources, are outlined. Subsequently, the SBMI tools and frameworks and the evaluation criteria are synthesized within an evaluation matrix.

Identified SBMI Tools and Frameworks

In the 28 articles that were identified through the systematic literature review, 21 different SBMI tools and frameworks are presented that presumably assist organizations when strategically implementing sustainability into their business models to create more SBMs. Table 1 provides an overview of the identified SBMI tools and frameworks.

Table 1. Tools and frameworks for SBMI identified through the systematic literature review.

Classification	SBMI tool or framework	Source
Object-oriented	Business Model Canvas (BMC) extended for infrastructure	[26]
	Cambridge Value Mapping Tool	[27]
	Dynamic business modeling for sustainability	[28]
	Ecocanvas as BMC for circular economy	[29]
	Flourishing Business Canvas	[30]
	Framework for sustainable circular business model innovation	[31]
	Sustainable Business Canvas	[32]
	SBM canvas	[33]
	SBM Pilot Canvas	[34]
	Sustainable Value Analysis Tool (SVAT)	[35]
	Sustainable Value Exchange Matrix (SVEM)	[36]
	Triple Layered Business Model Canvas (TLBMC)	[37]
Process-oriented	Back casting and Eco-design for the circular economy (BECE) framework	[38]
	Business Innovation Kit & Sustainability Innovation Pack	[39]
	Framework for strategic sustainable development (FSSD)	[40]
	Further development of the BECE framework	[41]
	Integrative Sustainable Intelligence Model (ISI)	[42]
	Value Ideation Process	[43]
Combination	FSSD - BMC	[44]
	CBMIP	[45]
	SVEM - ISI tool	[46]

In accordance with *Silvestre* [46], the SBMI tools and frameworks were classified as either process-oriented or object-oriented. Process-oriented tools and frameworks provide guidelines for integrating sustainability based on a sequence of stages. For every stage, the tool or framework provides guidelines for companies. One example of such a process-oriented tool is the ISI from [42]. The ISI model presents a set of procedures to aid in prioritizing sustainability integration efforts. Additionally, this tool highlights significant factors related to both internal and external stakeholders, specifically emphasizing the co-creation of value through the transfer of skills, knowledge, and experience [42].

Object-oriented tools and frameworks, on the other hand, provide a critical view on either a current business model or an intended business model and hence allow a diagnostical assessment. An example of such an object-oriented tool is the Cambridge Value Mapping Tool [27]. Through a structured and visual approach, this tool helps managers of an organization to gain a better understanding of both positive and negative aspects of an organization's value proposition for all relevant stakeholders, to identify conflicting values, and to identify opportunities for business model redesign [27]. As can be seen in Table 1, most of the identified tools and frameworks for creating SBMs are object-oriented.

While most tools and frameworks can be classified as either object-oriented or process-oriented, some tools and frameworks are combinations of object- and process-oriented tools and frameworks. The SVEM - ISI tool, for instance, is a tool based on the SVEM, an object-oriented tool, and the ISI model, a process-oriented tool. Other examples are the FSSD - BMC, a combination of the FSSD, a process-oriented tool, and the BMC, an object-oriented tool, and the CBMIP, which entails object- and process-oriented tools.

Six tools and frameworks (Ecocanvas as BMC for circular economy, Flourishing Business Canvas, Framework for sustainable circular business model innovation, TLBMC, FSSD - BMC, and SBM Pilot Canvas) are based on the BMC, a tool proposed by [47] that is very popular amongst practitioners for formulating business models. Through a visual representation of the different elements of a business model, as well as their interconnections and impacts on value creation, the BMC can help to understand an organization's existing business model [37]. In more recent years, several authors have developed SBMI tools and frameworks that are based on the BMC and add principles of sustainability into the original model. One example of such a tool that is based on the BMC is the TLBMC, a tool developed by [37]. Compared to the original BMC, the TLMBC contains two additional layers, an environmental layer, as well as a social layer. The environmental layer is built around a lifecycle perspective, while the social layer is built around a stakeholder perspective [30]. Another tool that builds on the BMC is the Flourishing Business Canvas. The Flourishing Business Canvas is a visual and collaborative tool that combines the traditional BMC with a focus on social and environmental impact and aims at creating business models that not only generate profits, but also contribute to a flourishing society and planet [30].

The identified tools and frameworks for SBMI display differences when it comes to the involvement of stakeholders, both internal and external, as well as the collaboration with partners, such as non-governmental organizations and companies along the value chain. While most tools encourage and expect organization's managers to consider the perspective of key stakeholders, other tools, such as the SVEM, entail the active participation of external stakeholders in workshops to obtain perspectives of outsiders [36]. The SVEM is applied in a workshop and supports reflections and discussions on how to impose sustainability into business models through a value exchange and multi-stakeholder approach in a structured and visual way [36]. Other tools, such as the FSSD and the FSSD - BMC can help organizations to expand their views on suitable partners while also fostering ideas for wider partnerships, including unconventional partnerships with public institutions [44]. The beforementioned ISI model entails a stage called "value co-creation", in which managers of the organization as well as internal and external stakeholders are interacting with each other [42]. This interaction between the organization and its stakeholders is expected to foster knowledge generation and transfer.

While most of the tools and frameworks cover all three business model elements (value proposition, value creation, and value delivery and capture), the Cambridge Value Mapping Tool solely focuses on the value proposition element of the business model while the other two business model elements, the value creation and delivery and the value capture, are not contemplated by the tool [27]. Some tools and frameworks proposed in the literature have been developed for a specific type of SBM, such as circular business models or product service systems. The framework for sustainable circular business model innovation, for instance, is a framework that assists organizations in the process of sustainable circular business model innovation by adding additional perspectives to the BMC that aid organizations in the recognition of trends and drivers at the ecosystem level as well as the understanding of the value to stakeholders by the business [31]. Other tools and frameworks were specifically designed for organizations in certain industries or in certain stages of the organizational life cycle, such as the Sustainable Business Canvas, which was specifically developed to be used by start-ups, or the BMC extended for infrastructure, a tool created for companies that are operating in the infrastructure industry [26,32].

Derivation of Evaluation Criteria

To identify the SBMI tools and frameworks that are most suitable for steel, cement, and chemical companies that are intending on utilizing regeneratively produced hydrogen in their production processes, evaluation criteria are required to evaluate the different tools and frameworks. The evaluation criteria are derived from several sources, such as the general characteristics of companies in energy-intensive industries, the challenges that organizations are often facing in the process of SBMI, as well as the insights that were gained through the identification of existing hydrogen projects of steel, cement, and chemical companies. Table 2 provides an overview of the abovementioned evaluation criteria.

Table 2. Derived evaluation criteria.

Number	Criteria
1	tool encompasses holistic investigation of the business model and its three elements
2	tool places special focus on value creation and delivery element of the business model
3	tool facilitates the identification of potential private sector partners
4	tool facilitates the identification of potential public sector partners
5	tool facilitates the identification of available public funds
6	tool was not explicitly designed for specific SBMI type other than SBM diversification
7	tool was not explicitly designed for the implementation of specific SBM type
8	tool provides guidelines for integrating sustainability based on a sequence of stages to support the sustainability integration process
9	tool was not designed to be used by companies in specific industry other than energy-intensive industries
10	tool investigates impacts on profits of the company, as well as impacts on society and the environment
11	tool entails testing, evaluation, and adjustment of new SBM prototypes
12	tool facilitates the integration of technology innovation with business model innovation

Evaluation Criteria 1: Tool Encompasses Holistic Investigation of the Business Model and Its Three Elements

The utilization of regeneratively produced hydrogen in the production of steel, cement, and chemicals impacts all three elements of the business model (value proposition, value creation and delivery, value capture). This impact differs from element to element and depends on the produced product. For instance, the production of steel through hydrogen direct reduction (H-DR) might require a steelmaker to build an entirely new production plant, while using regeneratively produced hydrogen in the ammonia synthesis might only require slight adaptations in the existing production facility. Hence, the adaptations of the value creation and delivery model are significant for the steelmaker, but rather small for the ammonia producer. At the same time, switching to H-DR might barely affect the steelmaker's value proposition. It is important for companies to assess the holistic impact that the utilization of green hydrogen in the production process has on their entire business model, and hence the three elements of it. Therefore, the SBMI tool or framework should entail a holistic consideration of all three elements of the business model.

Evaluation Criteria 2: Tool Places Special Focus on Value Creation and Delivery Element of the Business Model

The value creation and delivery element is at the heart of the business model since it enables the activities of the other two elements of the business model [17]. Before the use of green hydrogen necessitates adaptations in the value proposition and value capture element of the business model, the value creation and delivery element needs to be modified. A redesign of the value chain might be required to secure the supply with green hydrogen and production facilities might need to be built or at least modified to enable the use of green hydrogen in the production process. Therefore, it is beneficial if a SBMI tool or framework focuses on the value creation and delivery element of the business model.

Evaluation Criteria 3: Tool Facilitates the Identification of Potential Private Sector Partners

Radical innovations in energy-intensive industries are often perceived as costly and very risky. Single companies are often unable to carry these costs and high risks associated with radical innovation by themselves. Companies in energy-intensive industries hence often collaborate with competitors and technology providers, as well as public and private knowledge institutions when working on radical innovation [11]. The literature and practice review of existing green hydrogen projects of steel, cement, and chemical companies also revealed that companies tend to collaborate with several private and public sector partners across the value chain when trying to accomplish hydrogen projects. Since the use of regeneratively produced hydrogen requires renewable energy, it is not surprising that in the analyzed green hydrogen projects, steel and chemical companies always partner up with an energy provider, and often also with a manufacturer of electrolysers. An exemplary project identified through the literature and practice review is SALCOS, a project that was initiated by the German steelmaker Salzgitter AG. The overarching objective of this project is to produce CO_2-free steel through H-DR [48]. To achieve this, Salzgitter AG joined forces with partners from research and industry, such as the Fraunhofer Institutes IKTS, ISI, and UMSICHT, the French research center CEA, electrolyser manufacturer Sunfire, Avacon AG, a German energy supply company and the plant manufacturers Paul Wurth and Tenova [49]. Given the importance of private sector partners for steel and chemical companies to accomplish hydrogen projects, it is beneficial if the SBMI tool facilitates the identification of potential private sector partners.

Evaluation Criteria 4: Tool Facilitates the Identification of Potential Public Sector Partners

As described above under *evaluation criteria 3*, steel, cement, and chemical companies often not only collaborate with several private sector partners across the value chain to accomplish green hydrogen projects, but also with public sector partners. Especially when the utilization of regeneratively produced hydrogen in the production of steel and chemicals requires new and innovative technology, steel and chemical companies tend to collaborate with public research institutions, such as research institutions or government agencies. Hence, it is beneficial if the SBMI tool facilitates the identification of potential public sector partners.

Evaluation Criteria 5: Tool Facilitates the Identification of Available Public Funds

Radical innovations in energy-intensive industries are often viewed as expensive and risky endeavors, and single companies are often unable to carry these high costs and risks by themselves [11]. Besides, due to various interconnected factors, energy-intensive industries, except for the

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chemical industry, are often characterized by low investments into research and development [50]. Public funds can help companies in energy-intensive industries to cushion the high investment costs associated with hydrogen projects and lower the financial risk of radical innovation for companies in energy-intensive industries. The literature and practice review revealed that most existing hydrogen projects of steel and chemical companies receive substantial funds from national and supranational sources, such as the European Union. It is therefore beneficial if the SBMI tool facilitates the identification of available public funds.

Evaluation Criteria 6: Tool Was Not Explicitly Designed for Specific SBMI Type Other than SBM Diversification

SBMIs can be classified into four types: sustainable start-ups, where there's no existing business model and a new, SBM is created; SBM transformation, where an existing business model is transformed into a sustainable one; SBM diversification, where an existing business model stays in place, and an additional SBM is created, and SBM acquisition, where an additional, SBM is identified, acquired, and integrated [18]. The literature and practice review on existing green hydrogen projects revealed that the SBMI type utilized by steel and chemical companies is SBM diversification. No hydrogen project of a steel, cement, or chemical company was identified where a new organization with a SBM was established, the existing business model was immediately transformed into a sustainable one, or a SBM was acquired. Hence, it is not favorable if the tool or framework was specifically designed for any SBMI type other than SBM diversification.

Evaluation Criteria 7: Tool Was Not Explicitly Designed for the Implementation of Specific SBM Type

In their review of SBMI, [18] identified four different SBM types. These four SBM types are circular business models, social enterprises, bottom of the pyramid solutions, and product-service systems [18]. In recent years, researchers developed tools and frameworks specifically for the implementation of these SBM types. For instance, some SBMI tools and frameworks support companies that are aiming at imposing a circular business model. However, none of these four SBM types is in line with a SBM of a steel, cement, or chemical company in a hydrogen context. It is therefore not beneficial if the SBMI tool or framework was developed to foster the implementation of any of the mentioned SBM types.

Evaluation Criteria 8: Tool Provides Guidelines for Integrating Sustainability Based on a Sequence of Stages to Support the Sustainability Integration Process

In business practice, workshops and meetings for SBMI are often not followed up, which is one of the reasons for the design-implementation gap of SBMI [18]. Simultaneously, several SBMI tools and frameworks solely allow a diagnostical assessment by providing a critical view on either a current business model or an intended SBM. To successfully implement a SBM, a SBMI tool or framework that is comprised of several different stages and provides guidelines and support for every single stage is likely to be more suitable.

Evaluation Criteria 9: Tool Was Not Designed to be Used by Companies in Specific Industry Other than Energy-Intensive Industries

Companies that are operating in energy-intensive industries have certain characteristics that are rather unique and different compared to the ones that companies in some other industries possess. Amongst them is the fact that energy expenses often constitute the most significant cost factor for companies in energy-intensive industries [51]. Besides, companies in energy-intensive industries often collaborate with public and private sector partners when working on new or radical technologies and innovations since single companies often cannot carry the high research and development costs and the associated risk by themselves [11]. It is therefore not favorable if a SBMI

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tool or framework was developed explicitly to be used in a certain industry other than energy-intensive industries.

Evaluation Criteria 10: Tool Investigates Impacts on Profits of the Company, as well as Impacts on Society and the Environment

Companies struggle when trying to co-create profits, environmental benefits, and social benefits, and when moving towards SBMs, the balance amongst them is often challenging [52]. It is therefore beneficial if the SBMI tool or framework entails a thorough investigation of the impact on profits, as well as the environment and the society in the sense of the triple bottom line [53].

Evaluation Criteria 11: Tool Entails Testing, Evaluation, and Adjustment of New SBM Prototypes

The literature and practice review of green hydrogen projects of steel, cement, and chemical companies revealed that companies thoroughly test and investigate the utilization of regeneratively produced hydrogen in their production processes before they start investing larger sums. New potential production processes and technologies are tested on a small scale before the most promising production processes and technologies are scaled up. Therefore, it is favorable if the SBMI tool or framework entails a thorough testing, evaluation, and adjustment of new SBM prototypes.

Evaluation Criteria 12: Tool Facilitates the Integration of Technology Innovation with Business Model Innovation

The utilization of regeneratively produced hydrogen in the production of steel, cement, and chemicals often requires the implementation of innovative technology, such as H-DR. The integration of innovative technology with business model innovation, however, is complex, multidimensional, and one of the challenges that companies are facing in the process of SBMI [54]. Hence, it is ideal if the tool facilitates the often-difficult integration of technology innovation with business model innovation.

Evaluation of SBMI Tools and Framework

The identified SBMI tools and frameworks and the criteria to evaluate these tools and frameworks were brought together in the evaluation matrix that can be seen in Table 3. The objective of the evaluation is the identification of SBMI tools and frameworks that are most suitable for companies in the steel, cement, and chemical industry that are intending on using regeneratively produced hydrogen to produce their goods. To evaluate the tools and frameworks, the symbols "✓" and "-" were used in the evaluation matrix. When a SBMI tool or framework met a certain criterion, the tool or framework was labelled with the symbol "✓" in the respective field. If the tool or framework did not meet a certain criterion, it was labelled with the symbol "-" in the corresponding field.

The evaluation matrix reveals a wide variation of the tools and frameworks in terms of the number of fulfilled criteria. Some of the criteria are met by most tools and frameworks. Table 3 reveals that 19 out of the 21 tools and frameworks were not explicitly designed for a specific SBMI type (criterion six). The same number of tools and frameworks were not explicitly designed to be used by companies in a specific industry other than energy-intensive industries (criterion ten). 17 out of the 21 tools and frameworks were not explicitly designed for the implementation of a specific SBM type, such as a circular business model for instance. Criterion five and criterion twelve, on the other hand, are not met by any of the tools and frameworks. Only two of the 21 tools and frameworks, the Sustainable Business Canvas and the SBM Canvas, place a special focus on the value creation and delivery element of the business model (criterion two) and only one framework for SBMI, the CBMIP, entails the testing, evaluation, and adjustment of new SBM prototypes (criterion eleven). Existing SBMI tools and frameworks could be adapted and enhanced, or new tools and frameworks could be developed that meet these criteria.

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Some of the tools and frameworks are somewhat related to each other since they are based on the same tool. For example, the TLBMC, the FSSD - BMC, or the Flourishing Business Canvas are all based on the BMC. Hence, it is not surprising that several tools and frameworks share similar features and hence meet the same criteria.

With nine out of twelve criteria met, the CBMIP is the framework that fulfills most criteria. Hence, this is the SBMI framework that is most suitable for companies in the steel, cement, and chemical industry that are planning on introducing regeneratively produced hydrogen in their production processes. The CBMIP is a framework that was created to assist organizations in their SBMI endeavors and outlines the required steps and potential obstacles faced by organizations in each step [45]. The different phases of SBMI, from early conceptualization over detailed design to implementation are addressed by the CBMIP. It was developed by members of the Institute for Manufacturing of the University of Cambridge based on an extensive, systematic literature review followed by interviewing experts in the fields of industrial sustainability and business model innovation. In addition, the first three steps of the CBMIP were tested in a start-up with the objective of revealing valuable insights about potential enhancements of the framework.

The CBMIP serves both as a descriptive representation of how SBMI occurs in practice and as a prescriptive guide for how SBMI should be ideally executed in organizations [45]. Typically, the CBMIP is cyclical and iterative, meaning that after completion, most organizations will repeat it at some point to adjust or respond to changes in their industry and environment. Compared to other SBMI tools and frameworks, the CBMIP offers a more comprehensive guide, covering various stages of SBMI, their primary characteristics and components, key activities, the transition between different phases and steps, as well as potential challenges that may occur in the individual steps of the CBMIP. Additionally, the framework is highly pertinent for identifying and incorporating new and existing tools into a structured and synergistic portfolio that can effectively address challenges and support SBMI in organizations of varying sizes, industries, and contexts. In the ideation step, for instance, the Cambridge Value Mapping Tool, another SBMI tool, is integrated.

Table 3. Evaluation Matrix.

	1	2	3	4	5	6	7	8	9	10	11	12
	tool encompasses holistic investigation of the business model and its three elements	tool places special focus on value creation and delivery element of the business model	tool facilitates the identification of potential private sector partners	tool facilitates the identification of potential public sector partners	tool facilitates the identification of available public funds	tool was not explicitly designed for specific SBMI type other than SBM diversification	tool was not explicitly designed for the implementation of specific SBM type	tool provides guidelines for integrating sustainability based on a sequence of stages to support the sustainability integration process	tool was not designed to be used by companies in specific industry other than energy-intensive industries	tool investigates impacts on profits of the company, as well as impacts on society and the environment	tool entails testing, evaluation, and adjustment of new SBM prototypes	tool facilitates the integration of technology innovation with business model innovation
CBMIP	✓	-	✓	✓	-	✓	✓	✓	✓	✓	✓	-
FSSD - BMC	✓	-	✓	✓	-	✓	✓	✓	✓	✓	-	-
Sustainable Business Canvas	✓	✓	✓	✓	-	-	✓	✓	✓	✓	-	-
SVEM - ISI tool	✓	-	✓	✓	-	✓	✓	✓	✓	✓	-	-
Dynamic Business Modeling for Sustainability	✓	-	✓	✓	-	✓	✓	-	✓	✓	-	-
Flourishing Business Canvas	✓	-	✓	✓	-	✓	✓	-	✓	✓	-	-

SBM Canvas	✓	✓	✓	✓	-	-	✓	-	✓	✓	-	-
SBM Pilot Canvas	✓	-	✓	✓	-	✓	✓	-	✓	✓	-	-
SVEM	✓	-	✓	✓	-	✓	✓	-	✓	✓	-	-
TLBMC	✓	-	✓	✓	-	✓	✓	-	✓	✓	-	-
FSSD	-	-	✓	✓	-	✓	✓	✓	✓	-	-	-
Framework for sustainable circular business model innovation	✓	-	✓	✓	-	✓	-	-	✓	✓	-	-
SVAT	-	-	✓	✓	-	✓	✓	-	✓	✓	-	-
BECE framework	✓	-	✓	✓	-	✓	-	✓	✓	-	-	-
Ecocanvas as BMC for circular economy	✓	-	✓	✓	-	✓	-	-	✓	✓	-	-
Business Innovation Kit & Sustainability Innovation Pack	✓	-	-	-	-	✓	✓	✓	✓	-	-	-
ISI	-	-	-	-	-	✓	✓	✓	✓	✓	-	-
Value Ideation Process	-	-	-	-	-	✓	✓	✓	✓	✓	-	-
further development BECE framework	✓	-	✓	✓	-	✓	-	✓	-	-	-	-
BMC extended for infrastructure	✓	-	-	-	-	✓	✓	-	-	✓	-	-
Cambridge Value Mapping Tool	-	-	-	-	-	✓	✓	-	✓	-	-	-

4. Discussion

While this study contributes to the literature on SBMI, a relatively nascent field of research that is still considered to be in its infancy phase [18,55], several limitations should be acknowledged. Firstly, while some of the derived criteria are certainly more important than other, all criteria received the same weight. By assigning different weights to the criteria, the results of this study could have been refined. Additionally, one could argue that the results of the work at hand are rather theoretical. As mentioned previously, the first three steps of the CBMIP have been tested in a start-up in an attempt to reveal valuable insights and enhance the CBMIP. To the knowledge of the authors of this work, the CBMIP has not been tested in another organization in the context of a scientific study. Therefore, little is known about the practicability of the CBMIP, especially when it comes to the application in steel, cement, and chemical companies.

Future research could focus on sector-specific challenges, regulatory frameworks, market structures and stakeholder behaviour. In addition, the integration of sustainability goals into existing business models needs to be analysed. This requires analysing how companies can adapt their existing business models to integrate sustainability goals without negatively influencing their competitiveness. This includes the development of frameworks as a support tool for companies in the focus sector. In addition, there is a need to analyse the transferability and applicability of the SBMIs presented in this framework in other industries in the energy-intensive manufacturing sector.

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The analysis reveals that effective application of SBMI within the steel, cement, and chemical industries requires careful consideration of various factors. Furthermore, this work emphasizes the necessity for collaborative efforts among all stakeholders to fully realize the potential of green hydrogen. The identification of CBMIP as a suitable tool provides valuable guidance for firms facing the challenge of sustainably transforming their business models. Further would it be valuable to further test the CBMIP in the context of steel, cement, and chemical companies to evaluate its practicability and validate the results of this study. This could involve implementing the CBMIP in a case study setting and assessing its effectiveness in supporting SBMI resulting from the integration of green hydrogen into the production process.

5. Conclusions

In addressing the critical research question of which tools and frameworks for SBMI are most apt for companies within the steel, cement, and chemical industries in Germany intending to incorporate green hydrogen into their production processes, this study has underscored the imperative of decarbonization within these pivotal sectors. Through the execution of a systematic literature review, coupled with an assessment of extant green hydrogen projects and the application of SBMI tools and frameworks in an evaluative matrix, this thesis has identified the CBMIP as the framework most suitable for assisting these industries in the adoption of green hydrogen. This finding highlights the importance of tailored innovation processes that address not only the specific technological challenges but also the economic and social dimensions of sustainable transformation.

References

1. German Federal Government. Climate Change Act 2021: Intergenerational contract for the climate. Available online: https://www.bundesregierung.de/breg-de/themen/klimaschutz/climate-change-act-2021-1936846 (accessed on 14 April 2023).
2. Europäische Kommission: Der europäische Grüne Deal. Available online: https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0021.02/DOC_2&format=PDF (accessed on 18 July 2023).
3. Nilsson, L. J.; Bauer, F.; Åhman, M.; Andersson, F.N.G.; Bataille, C.; de la Rue du Can, S.; Ericsson, K.; Hansen, T.; Johansson, B.; Lechtenböhmer, S.; van Sluisveld, M.; Vogl, V. An industrial policy framework for transforming energy and emissions intensive industries towards zero emissions. *Clim. Policy* **2021**, *21*, 1053–1065. https://doi.org/10.1080/14693062.2021.1957665
4. Umweltbundesamt; Deutsche Emissionshandelsstelle. Treibhausgasemissionen 2022: Emissionshandelspflichtige stationäre Anlagen und Luftverkehr in Deutschland (VET-Bericht 2022). Available online: https://www.dehst.de/SharedDocs/downloads/DE/publikationen/VET-Bericht-2022.pdf?__blob=publicationFile&v=3 (accessed on 06 March 2024).
5. Hermwille, L.; Lechtenböhmer, S.; Åhman, M. et al. A climate club to decarbonize the global steel industry. *Nat. Clim. Chang.* **2022**, *12*, 494–496. https://doi.org/10.1038/s41558-022-01383-9
6. Mobarakeh, M. R.; Kienberger, T. Climate neutrality strategies for energy-intensive industries: An Austrian case study. *Clean. Eng. Technol.* **2022**, *10*, 100545. https://doi.org/10.1016/j.clet.2022.100545
7. Skorianz, M.; Engel, E.; Schenk, J. Sustainable steelmaking - A strategic evaluation of the future potential of hydrogen in the steel industry. Proceedings of the Iron and Steel Technology Conference, Cleveland, United States, 31 August to 03 September 2020. https://doi.org/10.33313/380/043
8. Agora Energiewende; Wuppertal Institut. Klimaneutrale Industrie—Schlüsseltechnologien und Politikoptionen für Stahl, Chemie und Zement; Wuppertal Institut: Wuppertal, Germany, 2019.
9. Smouh, S.; Gargab, F.Z.; Ouhammou, B.; Mana, A.A.; Saadani, R.; Jamil, A. A New Approach to Energy Transition in Morocco for Low Carbon and Sustainable Industry (Case of Textile Sector). *Energies* **2022**, *15*, 3693. https://doi.org/10.3390/en15103693
10. Gross, S. The challenge of decarbonizing heavy industry. Available online: https://www.brookings.edu/articles/the-challenge-of-decarbonizing-heavy-industry/ (accessed on 23 August 2023).
11. Wesseling, J. H.; Lechtenböhmer, S.; Åhman, M.; Nilsson, L. J.; Worrell, E.; Coenen, L. The transition of energy intensive processing industries towards deep decarbonization: Characteristics and implications for future research. *Renewable and Sustainable Energy Rev.* **2017**, *79*, 1303–1313. https://doi.org/10.1016/j.rser.2017.05.156
12. Wyns, T.; Axelson, M. *Decarbonising Europe's Energy Intensive Industries. The Final Frontier.*; Institute for European Studies Vrije Universiteit Brussel: Brussel, Belgium, 2016.

13. Hernández-Chea, R.; Jain, A.; Bocken, N.M.P.; Gurtoo, A. The Business Model in Sustainability Transitions: A Con-ceptualization. *Sustainability* **2021**, *13*, 5763. https://doi.org/10.3390/su13115763
14. Teece, D. J. Business Models, Business Strategy and Innovation. *Long Range Plan.* **2010**, *43*, 172–194. https://doi.org/10.1016/j.lrp.2009.07.003
15. Massa, L.; Tucci, C. L.; Afuah, A. A Critical Assessment of Business Model Research. *Acad. Manag. Ann.* **2017**, *11*, 73–104. https://doi.org/10.5465/annals.2014.0072
16. Evans, S.; Vladimirova, D.; Holgado, M.; van Fossen, K.; Yang, M.; Silva, E. A.; Barlow, C.Y. Business Model Innovation for Sustainability: Towards a Unified Perspective for Creation of Sustainable Business Models. *Bus. Strat. Env.* **2017**, *26*, 597–608. https://doi.org/10.1002/bse.1939
17. Bocken, N.; Short, S. W.; Rana, P.; Evans, S. A literature and practice review to develop sustainable business model archetypes. *J. Clean. Prod.* **2014**, *65*, 42–56. https://doi.org/10.1016/j.jclepro.2013.11.039
18. Geissdoerfer, M.; Vladimirova, D.; Evans, S. Sustainable business model innovation: A review. *J. Clean. Prod.* **2018**, *198*, 401–416. https://doi.org/10.1016/j.jclepro.2018.06.240
19. Schaltegger, S.; Hansen, E. G.; Lüdeke-Freund, F. Business Models for Sustainability: Origins, Present Research, and Future Avenues. *Organ. Environ.* **2016**, *29*, 3–10. https://doi.org/10.1177/1086026615599806
20. Reigstad, G. A., Roussanaly, S., Straus, J., Anantharaman, R., de Kler, R., Akhurst, M., Sunny, N., Goldthorpe, W., Avignon, L., Pearce, J., Flamme, S., Guidati, G., Panos, E., Bauer, C. Moving toward the low-carbon hydrogen economy: Experiences and key learnings from national case studies. *Adv. Appl. Energy* **2022**, *8*, 100108. https://doi.org/10.1016/j.adapen.2022.100108
21. Åhman, M.; Olsson, O.; Vogl, V.; Nyqvist, B.; Maltais, A.; Nilsson, L.J.; Hallding, K.; Skånberg, K.; Nilsson, M. Hydrogen Steelmaking for a Low-Carbon Economy: A Joint LU-SEI Working Paper for the HYBRIT Project; EESS report 109; Lunds Universitet: Lund, Sweden, 2018.
22. Labbe, M.; Mazet, T. Die Geschäftsmodellinnovations-Matrix: Geschäftsmodellinnovationen analysieren und bewerten. *Der Betrieb* **2005**, *58*, 897–902.
23. de Bruyn et al., S. Energy-intensive industries –Challenges and opportunities in energy transition, study for the committee on Industry, Research and Energy (ITRE); Policy Department for Economic, Scientific and Quality of Life Policies, European Parliament: Luxembourg, 2020.
24. Lechtenböhmer, S.; Samadi, S.; Leipprad, A.; Schneider, C. Grüner Wasserstoff, das dritte Standbein der Energiewende?. *Energiewirtschaftliche Tagesfragen* **2019**, *10*, 10–13.
25. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D. G. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *BMJ* **2009**, *339*, 332–336. https://doi.org/10.1136/bmj.b2535
26. Foxon, T. J.; Bale, C.; Busch, J.; Bush, R.; Hall, S.; Roelich, K. Low carbon infrastructure investment: extending business models for sustainability. *Infrastruct. Complex* **2015**, *2*, 1–13. https://doi.org/10.1186/s40551-015-0009-4
27. Bocken, N. M. P.; Short, S.; Evans, S.; Rana, P. A value mapping tool for sustainable business modelling. *Corp. Gov.* **2013**, *13*, 482–497. https://doi.org/10.1108/CG-06-2013-0078
28. Cosenz, F.; Rodrigues, V. P.; Rosati, F. Dynamic business modeling for sustainability: Exploring a system dynamics perspective to develop sustainable business models. *Bus. Strat. Env.* **2019**, *29*, 651–664. https://doi.org/10.1002/bse.2395
29. Daou, A.; Mallat, C.; Chammas, G.; Cerantola, N.; Kayed, S.; Saliba, N. A. The Ecocanvas as a business model canvas for a circular economy. *J. Clean. Prod.* **2020**, *258*, 120938. https://doi.org/10.1016/j.jclepro.2020.120938
30. Upward, A.; Jones, P. An Ontology for Strongly Sustainable Business Models: Defining an Enterprise Framework Compatible With Natural and Social Science. *Organ. Environ.* **2016**, *29*, 97–123. https://doi.org/10.1177/1086026615592933
31. Antikainen, M.; Valkokari, K. A Framework for Sustainable Circular Business Model Innovation. *Technol. Innov. Manag. Rev.* **2016**, *6*, 5–12. http://doi.org/10.22215/timreview/1000
32. Tiemann, I.; Fichter, K. Developing business models with the Sustainable Business Canvas: Manual for conducting workshops. In Proceedings of StartUp4Climate initiative, Berlin, Germany, 2016.
33. Bocken, N. Sustainable Business Models. In: *Decent Work and Economic Growth*, 1st ed.; Leal Filho, W., Azul, A.M., Brandli, L., Lange Salvia, A., Wall, T., Eds.; Springer Cham: Basel, Switzerland, 2021, pp. 963–975. https://doi.org/10.1007/978-3-319-95867-5_48
34. Baldassarre, B.; Keskin, D.; Diehl, J. C.; Bocken, N.; Calabretta, G. Implementing sustainable design theory in business practice: A call to action. *J. Clean. Prod.* **2020**, *273*, 123113. https://doi.org/10.1016/j.jclepro.2020.123113
35. Yang, M.; Vladimirova, D.; Evans, S. Creating and Capturing Value Through Sustainability. *Res. Technol. Manag.* **2017**, *60*, 30–39. https://doi.org/10.1080/08956308.2017.1301001
36. Morioka, S. N.; Bolis, I.; Carvalho, M. M. de. From an ideal dream towards reality analysis: Proposing Sustainable Value Exchange Matrix (SVEM) from systematic literature review on sustainable business models and face validation. *J. Clean. Prod.* **2018**, *178*, 76–88. https://doi.org/10.1016/j.jclepro.2017.12.078

37. Joyce, A.; Paquin, R. L. The triple layered business model canvas: A tool to design more sustainable business models. *J. Clean. Prod.* **2016**, *135*, 1474–1486. https://doi.org/10.1016/j.jclepro.2016.06.067
38. Mendoza, J. M. F.; Sharmina, M.; Gallego-Schmid, A.; Heyes, G.; Azapagic, A. Integrating Backcasting and Eco-Design for the Circular Economy: The BECE Framework. *J. Ind. Ecol.* **2017**, *21*, 526–544. https://doi.org/10.1111/jiec.12590
39. Breuer, H. Lean Venturing: Learning To Create New Business Through Exploration, Elaboration, Evaluation, Experimentation, And Evolution. *Int. J. Innov. Manag.* **2013**, *17*, 1-22. https://doi.org/10.1142/S1363919613400136
40. Broman, G. I.; Robèrt, K.-H. A framework for strategic sustainable development. *J. Clean. Prod.* **2017**, *140*, 17–31. https://doi.org/10.1016/j.jclepro.2015.10.121
41. Heyes, G.; Sharmina, M.; Mendoza, J. M. F.; Gallego-Schmid, A.; Azapagic, A. Developing and implementing circular economy business models in service-oriented technology companies. *J. Clean. Prod.* **2018**, *177*, 621–632. https://doi.org/10.1016/j.jclepro.2017.12.168
42. Silvestre, W. J.; Fonseca, A. Integrative Sustainable Intelligence: A holistic model to integrate corporate sustainability strategies. *Corp. Soc. Responsib. Environ. Manag.* **2020**, *27*, 1578–1590. https://doi.org/10.1002/csr.1906
43. Geissdoerfer, M.; Bocken, N. M. P.; Hultink, E. J. Design thinking to enhance the sustainable business modelling process – A workshop based on a value mapping process. *J. Clean. Prod.* **2016**, *135*, 1218–1232. https://doi.org/10.1016/j.jclepro.2016.07.020
44. França, C. L.; Broman, G.; Robèrt, K.-H.; Basile, G.; Trygg, L. An approach to business model innovation and design for strategic sustainable development. *J. Clean. Prod.* **2017**, *140*, 155–166. https://doi.org/10.1016/j.jclepro.2016.06.124
45. Geissdoerfer, M.; Savaget, P.; Evans, S. The Cambridge Business Model Innovation Process. *Procedia Manuf.* **2017**, *8*, 262–269. https://doi.org/10.1016/j.promfg.2017.02.033
46. Silvestre, W. J.; Fonseca, A.; Morioka, S. N. Strategic sustainability integration: Merging management tools to support business model decisions. *Bus. Strat. Env.* **2022**, *31*, 2052–2067. https://doi.org/10.1002/bse.3007
47. Osterwalder, A.; Pigneur, Y. *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*, 1st ed.; John Wiley & Sons: Hoboken, United States, 2010.
48. SALCOS® – Klimainitiative zur CO_2-armen Stahlproduktion. Available online: https://salcos.salzgitter-ag.com/de/ (accessed on 04 June 2023)
49. Redenius, A. SALCOS, WindH2, GrInHy – Wasserstoffprojekte bei der Salzgitter AG. *Prozesswärme* **2020**, *3*, 32–35.
50. Guevara, H. H.; Soriano, F. H.; Tuebke, A.; Vezzani, A.; Dosso, M.; Amoroso, S.; Grassano, N.; Coad, A.; Gkotsis, P. The 2015 EU Industrial R&D Investment Scoreboard. JRC Research Reports (2015).
51. Energiewende und Klimaneutralität als Herausforderung und Chance: Energieintensive Industrien. Available online: https://www.plattform-i40.de/Redaktion/DE/Artikel/Industrie/energieintensive-industrien.html (accessed on 06 March 2023)
52. Schaltegger, S.; Lüdeke-Freund, F.; Hansen, E. G. Business Cases for Sustainability: The Role of Business Model Innovation for Corporate Sustainability. *Int. J. Innov. Sustain. Dev.* **2012**, *6*, 95-119. https://doi.org/10.1504/IJISD.2012.046944
53. Elkington, J. *The Triple Bottom Line*, 1st ed.; Routledge: London, United Kingdom, 2004.
54. Evans, S.; Vladimirova, D.; Holgado, M.; Van Fossen, K.; Yang, M.; Silva, E. A.; Barlow, C. Y. Business Model Innovation for Sustainability: Towards a Unified Perspective for Creation of Sustainable Business Models. *Bus. Strat. Env.* **2017**, *26*, 597–608. https://doi.org/10.1002/bse.1939
55. Dentchev, N.; Rauter, R.; Jóhannsdóttir, L.; Snihur, Y.; Rosano, M.; Baumgartner, R.; Nyberg, T.; Tang, X.; van Hoof, B.; Jonker, J. Embracing the variety of sustainable business models: A prolific field of research and a future research agenda. *J. Clean. Prod.* **2018**, *194*, 695–703. https://doi.org/10.1016/j.jclepro.2018.05.156