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REVIEW

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Are strategy developers well equipped when designing sustainable supply chains for a circular bio-economy? Supporting innovations' market uptake in a PESTEL + I environment

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Abstract

Background Innovations and new supply chain concepts are crucial for establishing a sustainable and circular bio-economy that reduces carbon emissions and lowers negative environmental impacts. PESTEL-based concept development provides information about positive, negative and neutral external factors of the macro-environment and their influence on supply chains. The primary data were collected at a stakeholder workshop and gaps in understanding the critical details were closed through expert interviews. The information gathered was organised using a data management software and coded by following a deductively formed system based on predefined PESTEL categories (political, economic, social, technological, ecological, legal). Stakeholders that used the method on intermediate carbon carriers (ICC) grappled with identifying the obstacles that hinder the market uptake of innovations. The workshop revealed a substantial demand for additional information. Infrastructural aspects were considered key to adequately understanding all of the segments along a supply chain. Using PESTEL alone, without taking infrastructural aspects into consideration, meant that the macro-environment that surrounds and affects the ICC supply chain remained a black box. This paper developed docking-related approaches to the basic PESTEL method in order to improve its output for the development of strategic concepts and to improve the market uptake of bio-economy-centred innovations.

Results The expanded PESTEL method (hereinafter PESTEL + I) significantly shifted the emphasis of strategic decisions to the marketing of individual innovations compared to the basic method. Docking information gathering onto infrastructure (+ I) should be considered in order to expand existing strategy development concepts for bio-economy value chains. Testing the market uptake of innovations was beyond the scope of this study.

Conclusions PESTEL + I not only increased the utility, but also the complexity and the time needed to analyse an entire supply chain. The expanded method, however, provides stakeholders and strategy developers with a more useful tool to support and optimise market uptake strategies in the bio-economy. Beyond this, there is a knowledge gap with regard to reducing the effort needed to collect data and evaluate such studies. Hence, follow-up research needs to find ways to digitalise major steps in the overall process to make it more efficient.

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Keywords Bio-economy innovations, Market uptake, Strategy development, Intermediate carbon carriers, Biomass supply chain

Background

The 2015 Paris Agreement was a breakthrough that sped up treaties and regulations and accelerated progress and innovation in climate action, sustainable development, and the implementation of adequate supply chains [1]. For example, the European Union (EU) established nationally determined contributions (NDC) for its members in 2016 and updated this programme in 2020 with more ambitious targets. The European Green Deal (EGD, 2019) aims to have Europe become the first climate-neutral continent by 2050. That requires Europe to reduce at least 55% of its net emissions by 2030 [2]. The EU 2018 Bio-economy Strategy is the underlying master plan for implementation [3]. It highlights the importance of establishing a sustainable and circular bio-economy. This includes transitioning away from using fossil resources towards using biogenic and renewable resources in the production of both goods and energy in line with the sustainable development goals (SDG). This requires innovative financing, technology and sustainable development frameworks [4]. Optimized use of waste and residues, for instance as sources of intermediates for the bio-economy, is an intrinsic element of the strategy [5, 6]. In terms of carbon cycling through the economy, these intermediates, which are derived from residual and waste biomass, are generally considered to be intermediate carbon carriers (ICC). When they are used for energy, they are considered intermediate bioenergy carriers (IBC) [7]. In the field of thermo-chemical conversion, numerous technologies have been invented to produce ICCs, including gasification, pyrolysis (e.g., torrefaction), combustion and liquefaction [8]. Notably, many of these technologies face severe challenges when entering the market [9], and strategy developers have to screen and clear barriers along the path from invention to innovation. For example, stakeholders in bio-economy supply chains may hesitate turning to ICCs because established sources and cost-efficient technologies are in place or are still available on the market in sufficient quantities [7, 8]. At the same time, changes in the interwoven bioeconomic networks and their market environment mean that strategy developers are facing higher complexities. This requires a multi-level analysis (a) of the socio-technical transition [10, 11], including the interaction between three levels, such as emerging innovative niches, existing socio-technical regimes, and external developments (e.g., political landscapes). Furthermore, (b) attention must be paid to additional social and organisational aspects [12], and (c) to interpretations of expected sustainability gains [13]. All of these aspects have to be considered since technological innovations do not appear in isolation. Instead, they are embedded in social economic and political contexts that affect their trajectories and outcomes. By considering these endogenous and exogenous factors, the multi-level perspective provides a more comprehensive understanding of the innovation process, including the role of stakeholders, networks and institutions [10]. In one promising approach, D'Adamo et al. [14, 15] developed an indicator system to evaluate the socio-economic performance of a value chain at the regional level.

Intermediate carbon carrier (ICC) supply chains

The term ICC was coined within the EU H2020 funded project "Market Uptake Support for Intermediate Bioenergy Carriers" (MUSIC). With the focus on new supply chain concepts for biomass, which can be converted into three types of intermediate bioenergy carriers, ICCs demonstrate that intermediates must now feed carbon into both energy production and, increasingly, into material production.

Supply chains include all suppliers, producers, distributors, their related activities and processes, as well as end-users [16]. In strategy development it is useful to separate biomass supply chains into upstream, conversion and downstream segments (Fig. 1). Upstream processes include the harvesting, collection, transportation, storage and pre-processing of biomass. Downstream processes include distribution/transportation of bioenergy/biofuels and related products of biogenic origin to the end customers directly or through storage facilities [16]. This entire environment of stakeholders, activities and processes affects the feasibility of new supply chains as well as the market uptake of innovations.

Turning invention into innovation by opening the "black box"

ICCs are regarded as a prime opportunity to increase sustainability in the industry and the energy sector. Many ICC production technologies remain "inventions" insofar as their commercial scale is still under development and/or their market uptake as an "innovation" has not been successful [18]. Thus, it is crucial to answer the question "How can ICC-related inventions be brought to the market successfully?" Wahl sees the problem as the starting point for a problem-solving process that results in an invention [19]. In line with this idea, an invention

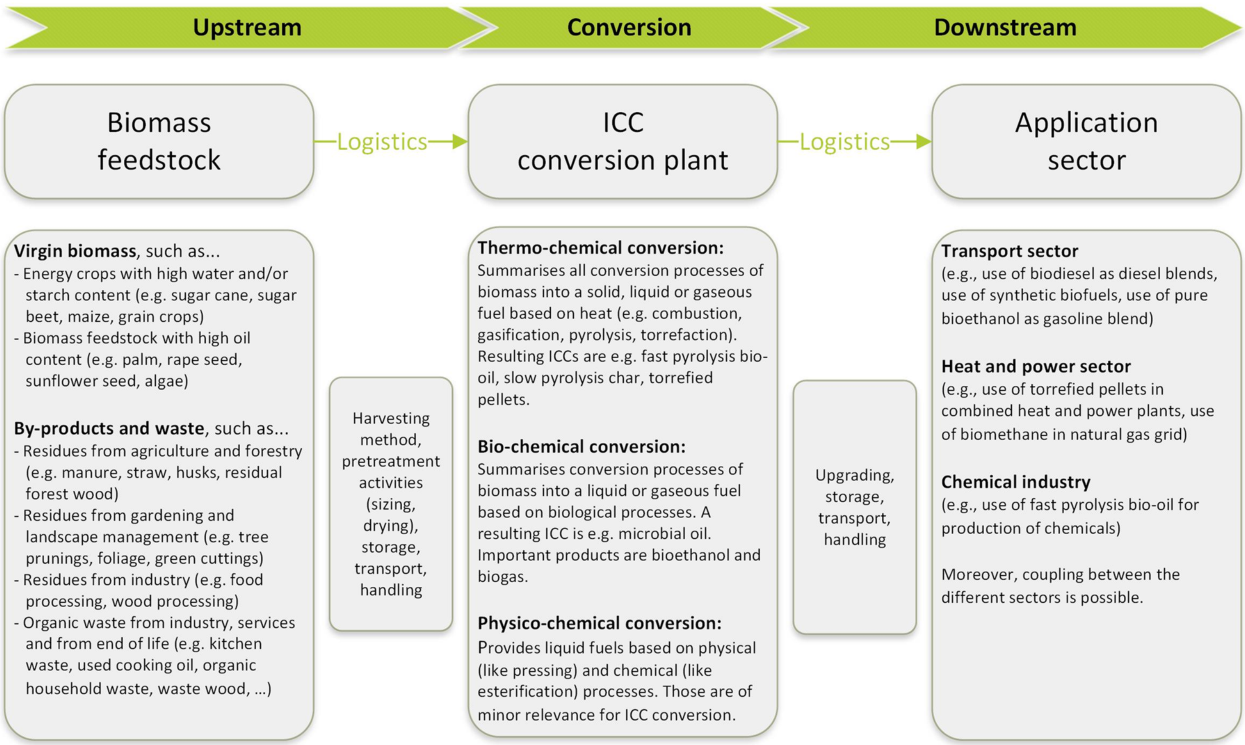


Fig. 1 Generic biomass supply chain of ICCs (redrawn with reference to [17])

is also the creation of problem-solving potential. In the context of the here examined value chain, the problem is "the replacement of fossil resources by biomass-based energy and products". ICC-related technologies represent the problem-solving potential which needs investment in order to prepare for production and market access [20]. Investment carries the invention through production, marketing and market launch, and is only rewarded when successful market uptake turns into an innovation [21, 22].

A systematic approach is necessary to identify the biggest enablers and hindrances for establishing innovations in a given market environment. Oppenländer outlined the system, which consists of an organisation, key stakeholders in the environment, and existing dynamics between them [22]. This "black box" needs to be opened in order to identify the processes conducive to economic growth and innovation (Fig. 2).

The invention and its effective environment

The EU is strongly focused on using renewable fuels in order to create a sustainable and circular bio-economy. However, renewable is not the same as sustainable, and "sustainable development" has many definitions depending on the context [23]. A report by the World Commission on Environment and Development, also known as "Report", contains one frequently used definition: "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [24]. More recently, the European Renewable Energy Directive (RED II) has put renewable energies and their sources into the context of the economy and financing, ecology, society and politics [25]. A quite comprehensive picture develops from the relation between renewable energies and the environment in which they are embedded. The application of the expanded PESTEL+I method presented in this study highlights the challenges, interrelations and major bottlenecks facing new value chains, especially when it comes to infrastructural issues. It outlines the range of factors that need to be analysed before decisions can be made about an organisation's development towards sustainability. As the success of an organisation or company hinges on its strategies [26–28], assessing future perspectives and identifying potential factor developments are necessary so that they can be appropriately taken into account [28]. Thus, entrepreneurial spirit and creativity are needed alongside an understanding of an organisation's operational and multi-level environment, now and in the future. Organisations are influenced by their environment to varying degrees [29]. It is therefore important to differentiate between external elements (in

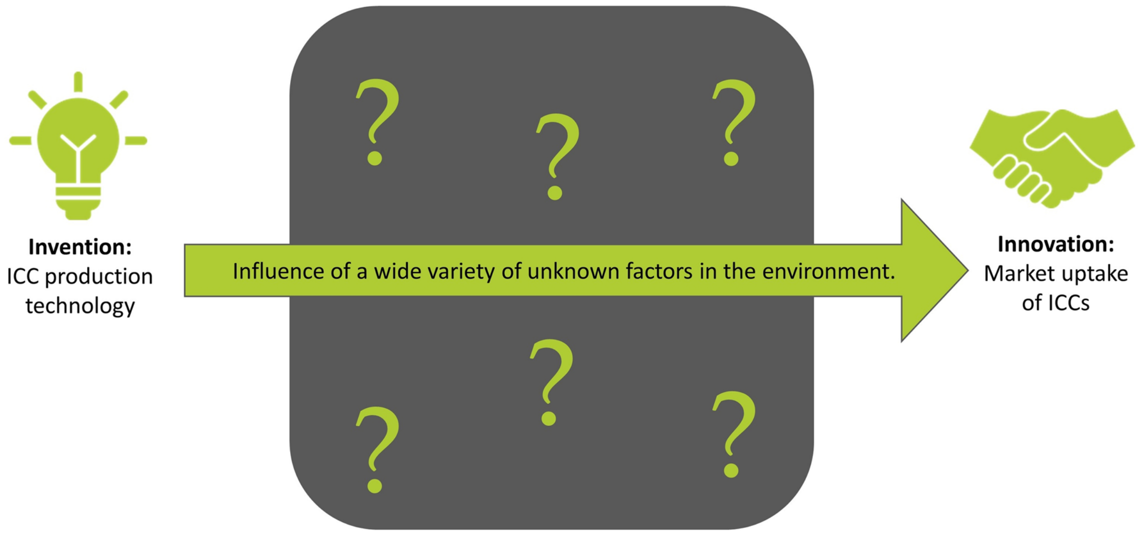


Fig. 2 The "black box" as an initial framework

the environment) and internal elements (in the organisation, e.g., physical and human resources). Concerning the external elements, Hungenberg and Wulf regard organisations as part of a comprehensive whole, which means they relate to a sector, operate in a certain environment, and are affected by multiple factors [29]. This includes an organisation's relation to and interactions with its stakeholders, consumers and competitors. Similarly, the resource dependency theory (RDT) explains the dependency on factors and actors in the external environment, especially in terms of access to urgently needed resources [30]. The RDT's general concern with "the relationship between an organisation and a set of actors in the environment" [31] is specified in "transactions and structural relationships that exist between buyers and sellers" [32]. The importance of all-encompassing strategic analyses for business development and the marketing of innovations has been underscored repeatedly.

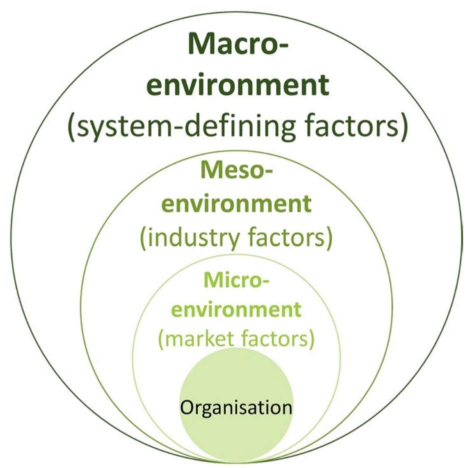


Fig. 3 The different environments of the outside-in analytical framework (adapted from [28])

Dimensions of the environment

For a strategic analysis using an outside-in analytical framework, it is useful to break down the complexity of an organisation's interactions with its external environment into macro-influences, meso-influences (firms and consumers influence the industry) and micro-influences (firms competing in the same industry as the focal firm) [26]. The different spheres of influence are redrawn in Figs. 3 and 6. The macro-environment comprises "global"—in the sense of system-defining—factors that are important for the development of the organisation or the industry itself, but which concomitantly affect many other companies [33]. Organisations or industries cannot revise the factors as these are predetermined operational frameworks. The term macro-environment essentially encompasses political, legal, economic, technological, social and ecological/natural influences [27]. In contrast, the meso-environment describes factors that frame an organisation's immediate competitive environment. Here the analysis focuses on, for instance, the upstream and downstream supply chain (Fig. 1). In a two-way interaction, customers, suppliers and competitors are able to influence the way an organisation markets its products or services. Conversely, the organisation can affect the other stakeholders [30]. The micro-environmental level is also called "markets" in which an organisation's direct competitors are located [27].

In order to achieve transparency and to reflect the multi-dimensional environment, specifically the macro-environment, it appeared necessary to expand a proven method (i.e., PESTEL). A research gap was identified where the influence of the macro-environmental factors on whole supply chains and not only organisations or products needed to be defined. Successful market uptake of bio-economy supply chains requires the development of novel approaches and methods that increasingly concentrate on infrastructural aspects. Against the backdrop of a continuously changing regulatory framework [25], the method's expansion aimed primarily at (a) supporting strategy developers in the development of innovation marketing in ICC supply chains, and (b) at ensuring the applicability of the new approach, as an explicit need for certain additional information is likely to surface in the strategic development of other industries, too.

Method

There are several methods and approaches that enable scientists and economists to analyse different levels of an organisation's environment.

Examples of methods and approaches for analysing the environment

The PEST approach is a strategic management method [28] that was first mentioned in its original form in 1967. In his book "Scanning the business environment", Harvard professor Francis Aguilar divided the macro-environment into four groups of influencing factors, namely the categories of economic, technical, political and social factors – constituting the acronym ETPS [34, 35]. Later, the Arnold Brown Institute of Life Insurance adapted it by changing the order to social, technological, economic, political (STEP) and evaluated trends in a strategic way. The method has been adapted several additional times, which has resulted in a variety of acronyms: PEST, STEPE ("ecological" was added), PESTLE or PESTEL ("legal" was added in the 1980s), STEEPLE ("ethical" was added) and ESTEMPLE ("media" was added) [26, 35]. This variety of the PEST method proves the flexibility of the approach. Categories were added or removed and ordered according to research needs [36].

A possible approach to analysing the industry in which organisations as well as markets are embedded is described as Porter's Five Forces (P5F). The P5F method allows an industry's attractiveness to be evaluated based on competitive forces. More precisely, the bargaining power of buyers and suppliers, the threat of new entrants and substitutes, as well as rivalry among existing organisations within the industry are called the five forces. According to Porter, an industry is only attractive to competition if the forces are low, competition is not too strong, and the pressure to make a profit is not too high [28].

On the lowest level of a market environment, a SWOT analysis can effectively summarise an organisation's internal strengths and weaknesses as well as the external opportunities and threats it has to face [37]. A SWOT analysis can be particularly useful if an organisation wants to compare itself to direct market competitors and to identify comparative advantages [26]. This approach can help support a change in organisational strategies aimed at business success [38].

Using the PEST method to analyse the environment of sustainable supply chains

The outside-in analytical framework, i.e., the PEST method, constitutes a well-established approach for analysing an organisation's complex macro-environment that is continuously in flux. This method enables insights to be gained into the roles of the relevant players as well as the general framework conditions. This helps to identify the factors that are regarded as driving forces of change and to predict an organisation's future developments [39]. By identifying these factors, strategies can be developed in reaction to the changing macro-environment. As this study aims to support strategy development, the main emphasis lies in identifying appropriate driving factors. Hence, the PEST method, or one of its modifications (e.g., PESTEL), should be used. However, the original version of this method is insufficient, as it purely focuses on a single organisation or product. To fill the gap, the present study enhanced the PESTEL method and applied the approach to the context of an entire supply chain, e.g., the ICC supply chain.

Data collection

For our analysis, data needed to be collected on macro-environmental factors that might affect the decision-making process of strategy developers with regard to the market uptake of ICC technologies [7, 40]. Therefore, an initial stakeholder workshop was held as part of the MUSIC project to gather information on macro-environmental factors and to order them into the PESTEL categories (political, economic, social, technological, ecological, legal) [4]. A coding scheme for each PESTEL category and code-specific definitions were discussed and adjusted in a mutual exchange with the participants (Table 1). Relevant players of the targeted market were then determined in a step-by-step process. At first, the stakeholder categories were defined in stakeholder factsheets [41] (Table 2). These categories included upstream stakeholders (feedstock providers), conversion stakeholders (technology companies, producer companies, research) and downstream users (refineries,

Table 1 Overview of PESTEL and SWOT/TOWS categories/codes (adapted from [7, 27, 28])

Factor category	General description	Examples with regard to ICCs
PESTEL	Method of strategic management to analyse the macro-environment	
Political (P)	Role of state/government ("guiding")	Governmental subsidies, consumer incentives, taxation regulations, trade barriers
Economic (E)	Macro-economic perspective	Prices of alternative products, economic growth (rate), number of jobs, exchange rates, taxation, competition, resource availability, number of plants and their capacities, life cycle costing, pre-treatment costs vs. feedstock prices (biomass specifications – strong link to the factor category "technological"on the left side)
Social (S)	Changing cultures and demographics	Changes in social thinking, consumer convenience, population growth, income distribution
Technological (T)	Innovations	Cost comparison of plants, number of different technologies, fields of research and their costs, new products/processes/materials – innovations, flexibility of plants and feedstock, product life cycles, governmental research expenditures, biomass specifications (pre-treatment costs vs. feedstock prices—strong link to the factor category "economic" on the left side)
Ecological (E)	"Green" issues concerning the natural environment (like environmental pollution, generating waste, sustainability criteria etc.)	Advantages and disadvantages of ICCs compared to conventional heating fuels, cultivation criteria, waste/residues, life cycle assessments
Legal (L)	Statutory restrictions/changes ("restricting")	Statutory requirements for ICCs or for the end-products produced from ICCs (on the downstream side of the supply chain)
SWOT/TOWS	Framework used in the strategic planning of an organisation or product	
Internal strength (S)	Enabler	Internal factors supporting the market uptake, e.g., technology advantages, feedstock flexibility, cost-efficiency
Internal weakness (W)	Barrier	Internal factors hindering the market uptake, e.g., technology challenges, slow upscaling, difficult storage and handling
External opportunity (O)	Enabler	External factors supporting the market uptake, e.g., favourable policy regulations, collaborations, subsidy, quotas
External threat (T)	Barrier	External factors hindering the market uptake, e.g., unfavourable policy regulations, rising material costs, increasing technology & feedstock competition

Table 2 Overview of stakeholders that participated in the initial workshop

Stakeholder (SH) ID	Stakeholder group affiliation	Participation in workshop	Participation in follow-up interview
SH 01	Downstream		x
SH 02	Politics		x
SH 03	Other (industry network)	x	x
SH 04	Service provider (logistics)	x	x
SH 05	Service provider (logistics)	x	x
SH 06	Service provider (technology)	x	x
SH 07	Service provider (technology)	x	x
SH 08	ICC producer & Downstream	x	x
SH 09	Upstream	x	x
SH 10	Upstream	x	
SH 11	Research	x	
SH 12	Research	x	
SH 13	Service provider (logistics)	x	
SH 14	Other (industry network)	x	

transport sector) as well as service providers (networking, technology), policymakers (ministries, associations) and society (non-governmental organisations). Then the MUSIC project partners identified the stakeholders relevant to a specific ICC value chain within the case study region of the MUSIC project [7]. This list was expanded by further experts via snowball sampling and through internet research. This resulted in regional maps of bioenergy settings [42] and a complete stakeholder list [43].

Interviews were held with experts in order to verify the data collected during the workshop and to supplement the primary data collection with additional market-relevant information. Data was triangulated during the analytical process to avoid bias or the influence of a single perspective [44, 45]. The interviews were conducted in a semi-structured manner to allow for greater flexibility with regard to the topics to be discussed, in particular the respondents' expertise and availability [46]. For this purpose, a set of questions was prepared ahead of the interviews. An additional file provides an overview of possible questions (see Additional file 1).

Table 2 provides an overview of the stakeholders that supported the collection of the primary data through their participation in the initial online workshop, following online or face-to-face events, or by providing information in expert interviews.

Coding information into PESTEL and SWOT categories

The investigation of the supply chain environment required that a large set of qualitative data be collected and assessed. In order to handle such a large amount of data, which can be expected in such studies, the PESTEL analysis process was supported by "computer assisted qualitative data analysis software" (CAQDAS) [47] through a data management package. The decision was made to manage the data in this study using the qualitative data analysis software "NVivo" [48], which allows for the importation of different types of data. In addition to text files, other formats like audio and video files as well as web content can be imported. Working with this software can be regarded as an ongoing procedure because different sources are imported and coded in a step-by-step process. Paragraphs, sentences, notes, figures and tables were coded for the PESTEL and SWOT categories (Table 1) within the data sources (e.g., interview notes, peer-review articles, other publications). Initial conclusions were drawn and collected in memos based on the relations between the sources and/or codes that were identified.

The definition of analytical categories and sub-categories plays a crucial role. In NVivo, categories are called codes and they support the process of organising, sorting and the subsequent retrieval of sections of text. The composition and characteristics of the code systems depend greatly on the aim of the user. A decision must be made as to whether the codes are allowed to overlap or if they should be mutually exclusive. Moreover, it must be decided whether the code system is created inductively, based on the imported text sources or deductively, according to a scientifically established categorisation system [49].

A PESTEL analysis was applied in our study in order to understand the macro-environment of the analysed supply chains. Thus, a code system was devised that allowed different codes to overlap and it was formed deductively, based on the predefined PESTEL categories (Table 2). To generate inter-reliability and to validate the results, multiple researchers worked on one NVivo project simultaneously and various data sources were used [44, 45]. Each code was clearly defined in order to avoid misunderstandings and to ensure logical and transparent coding by all users. An overview of the code definitions as well as some examples are given in Table 2.

As the aim is not only to depict the macro-environment that shapes the ICC supply chains, but also to support strategy development for the successful market uptake of ICCs, the deductive code system was enhanced by the four SWOT categories internal strengths (enabler), internal weaknesses (barrier), external opportunities (enabler) and external threats (barrier) (Table 1). This enabled factor allocation to both the PESTEL and SWOT/TOWS codes. TOWS is SWOT spelled backwards and supports strategy development by matching internal strengths and weaknesses with external opportunities and threats (maxi-maxi strategy: maximising opportunities by using particular strengths, mini-maxi strategy: minimising weaknesses by using opportunities, maxi-mini strategy: using particular strengths to minimise threats, mini-mini strategy: minimising weaknesses and avoiding threats (Fig. 4)). Applying this procedure created the basis for strategy development and the formulation of recommendations for different stakeholder groups within a TOWS matrix (Fig. 4).

Results

Enhancement of a macro-environmental analysis to PESTEL + I

All of the PESTEL categories and related code definitions were discussed and elaborated on during the initial stakeholder workshop, which was held within the framework of the MUSIC project. There was a particularly pronounced interest in logistical issues when economic and technological aspects were discussed. Logistics often represents a major hurdle in the supply of biomass. It is often quite bulky and has a low energy density. In contrast, ICCs are beneficially compact (high bulk density). They

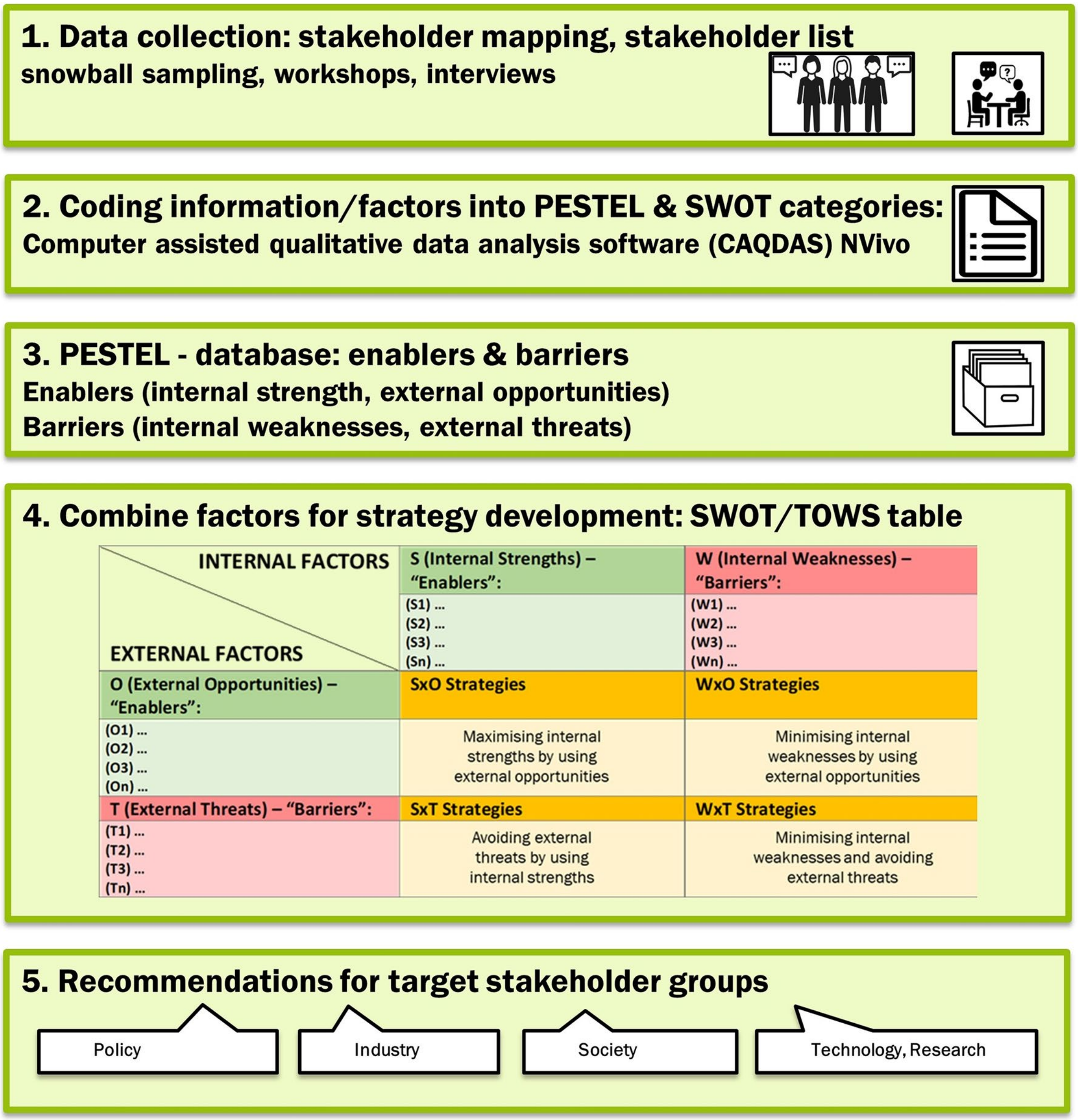
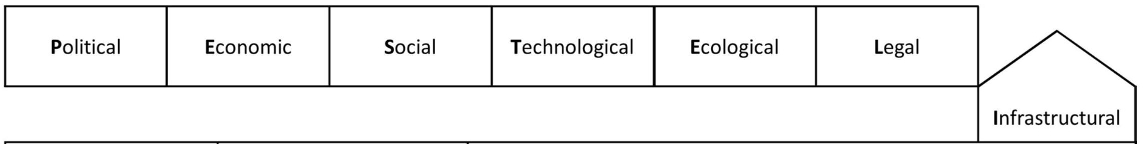


Fig. 4 Description of the applied methodology

also have a higher energy density than raw biomass. But their main advantage in terms of further processing (their unique selling point) is their homogeneity. Compared to a mix of different kinds of virgin biomass, which is difficult for some processes to handle, ICCs are a comparably uniform and easy-to-handle feedstock when it comes to transport, storage and processing in a conversion plant.

When analysing the data relevant for market uptake (which was gathered through further workshops, interviews and literature), it became clear that a lot of the information related to the bio-economy value chain referred to issues like harvesting practices, road conditions, means of transport, container sizes, handling particularities, storage capacities, requirements of feedstock for storage, et cetera. Therefore, the researchers decided to modify the deductive code system in NVivo by adding the category "infrastructural". Thus, the PESTEL analysis was enhanced to PESTEL + I so as to include infrastructural aspects, as shown in Fig. 5. Siegfried et al. provide an exemplary, case study-specific list of macro-environmental factors [7].



Factor category	In general	Examples with regard to ICCs
Infrastructural	Locations, routes, transportation costs	Near to harbour/railway network/main traffic roads/airports, near to feedstock supplier, resulting transportation routes for exports, resulting costs for transportation (strong link to "economic")

Fig. 5 Expansion of the PESTEL analysis approach by adding "I" (Infrastructural) to create PESTEL + I

Relevance of the entire supply chain within a complex macro-environment

During workshops and interviews, the question always arose as to how certain sector demands in the downstream segment of the supply chain (e.g., share of advanced biofuels in the transport sector, as required by RED II) can be aligned with the available biomass feedstocks in the upstream segment of the supply chain. The (ICC) conversion plant operator is always situated between these two segments. Hence, the plant operator is very dependent on what is supplied in the upstream segment and what is demanded in the downstream segment of the supply chain, similar to what is explained by the resource dependency theory [30, 31]. Accordingly, not only should the plant operator be a focus of consideration, but also all steps prior to and after the actual conversion. During several stakeholder engagement workshops, it became clear that no part of the supply chain should be neglected when discussing the market uptake potential of ICCs. For instance, certification plays an important role in the upstream segment of the supply chain when it comes to estimating the greenhouse gas emission reduction of biomass sourcing. Certification is also key at the conversion site because the ICC conversion plant needs to prove that it is operating in an environmentally friendly way. And finally, the certification of end products, as well as standards for transport and storage, play a crucial role at the downstream site because this improves market acceptance and possibly increases the number of product applications and sales opportunities. Even if complying with certification requirements (such as the standards of the International Organisation for Standardisation) is not obligatory, meeting these requirements would highly aid in the market uptake of ICCs.

Integration of innovative supply chain concepts in an enhanced macro-environmental analysis

The existing approaches and concepts have been expanded and integrated into each other for two main reasons: (1) the workshop's discussions revolved around infrastructural aspects and (2) stakeholders highlighted the need to consider each part of the supply chain when talking about market uptake of innovative technologies and products in the bio-economy. Thus, the outside-in analytical approach does not focus on a single organisation, but on a whole supply chain. The PESTEL method used in this approach is complemented by the category "infrastructural". Figures 5 and 6 provide an overview of the modified analysis approach, which combines the outside-in analytical framework, including the enhanced PESTEL + I method, with an entire supply chain, consisting of an upstream, conversion and downstream segment.

Discussion

The bio-economy offers great opportunities for solving current social, economic and ecological challenges [50]. Sustainable implementation of related innovative supply chains (e.g., ICC, Fig. 1) are crucial for the establishment of a sustainable circular bio-economy. This can only be achieved by analysing multiple levels and criteria of the macro-environment and by considering region-specific particularities [13, 14]. Authors have pointed out that the PESTEL framework alone in its current form may not be adequate enough, and further research and optimisation may be required [35, 51, 52]. The challenges related to performing a PEST analysis are described by Ho [51]. The necessity for a clearer definition and measurability of indicators for the PESTEL categories and a need to better define the relative importance of factors have been mentioned as well [35, 52]. We clearly see that value chain environments are extraordinarily complex. They are not only dependent on political, economic, social, technological, ecological and legal framework conditions, but also infrastructural factors and multiple-level perspectives have to be considered as well in order to obtain a comprehensive picture [11, 12]. By shedding light on the black box through an expanded PESTEL + I approach, we contribute to supporting the market uptake of ICC inventions and thus help them to become market-ready innovations in the bio-economy. This creates a clear picture of

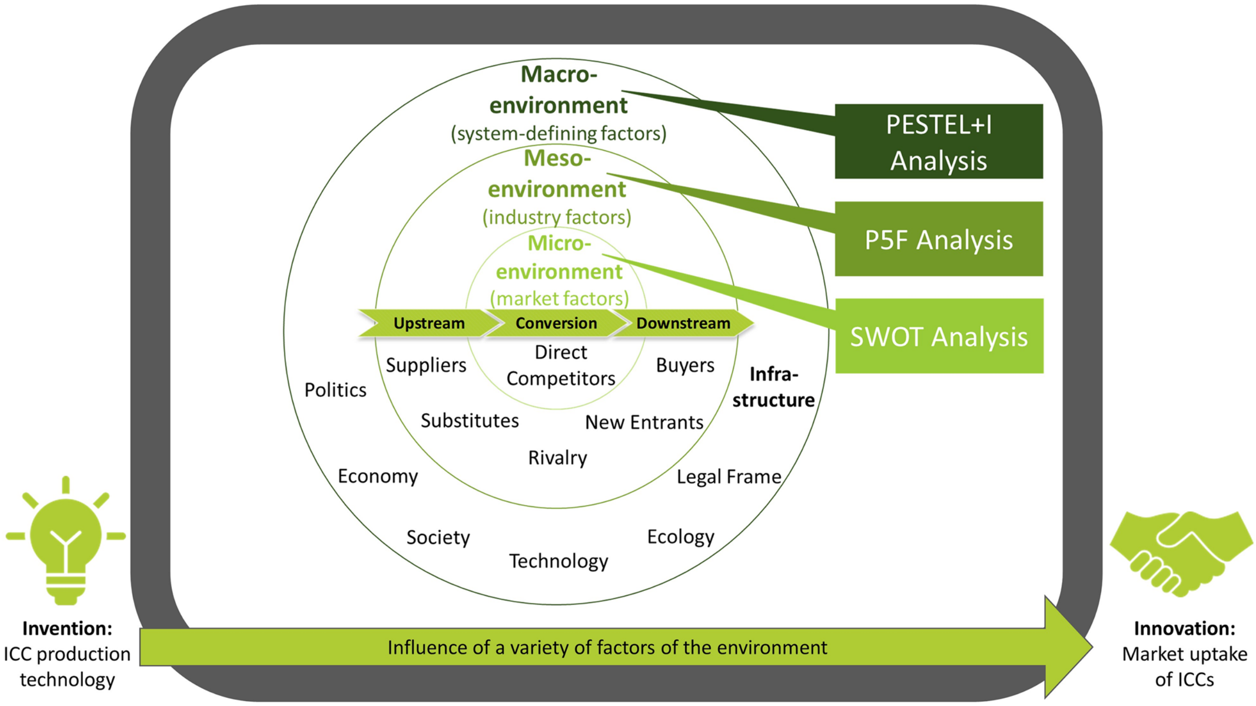


Fig. 6 Extending PESTEL by adding "Infrastructure" and focusing on the entire supply chain to open the black-box

the macro-ecological framework conditions and provides much better support to strategists developing innovative bio-economy supply chain concepts.

As the macro-environmental analysis provides the big picture, quite a broad view is taken. The need to cover all of the three environmental dimensions emerged during workshops and interviews: people unintentionally switched between the different environmental dimensions during the discussion, which was actually targeting potential macro-environmental influences (PESTEL+I factors). In doing so, the need for a close interlinking between the different dimensions of the environment became clear. For instance, conducting a P5F analysis after the PESTEL+I analysis could represent a good option so that a clearer picture of the ICC industry can be obtained. By applying a P5F analysis, relevant feedstock and technology providers on the upstream supply chain side, as well as buyers that further process/upgrade the ICCs, and (end-)consumers in the downstream segment can be identified across Europe. Moreover, the rivalry between the ICC production plant and its competitors can be addressed.

In our analysis, macro-environmental (and meso-environmental) enablers and hindrances identified through the PESTEL+I analysis were sorted into strengths, weaknesses, opportunities and threats (SWOT) in order to obtain a condensed picture regarding further planning and strategy of ICC market uptake [7]. As the developed methodological framework can be regarded as a kind of blueprint, the case study-specific application and results of the PESTEL+I, SWOT and TOWS methods are given by Siegfried et al. [7], in which fast pyrolysis bio-oil (FPBO) represents the ICC [53]. Here, an ICC supply chain of FPBO that is produced from forest residues and then upgraded into a biofuel for the maritime sector is considered. More practice-related applications are necessary in order to further develop and improve the application of the method in other value chains of the bio-economy.

The resulting factors on the macro-level are regarded as a very good starting point for further investigations to support market uptake of ICCs and other value chains in the bio-economy. However, it is important to keep in mind that the developed approach also has some limitations: (1) the allocation of single factors to the PESTEL+I categories is rather subjective. Sometimes, identified environmental factors overlap or cannot be strictly separated from one another. Here, only the justification of allocating a factor to one category instead of another is important. However, the different options that may arise when allocating factors to the PESTEL+I categories do not directly influence the strategy development, as the PESTEL+I method mainly supports the structured investigation of the environment in order to obtain a comprehensive picture. (2) On the other hand, the analysis is only able to represent the current status. Therefore, strategy developers, who are analysing an organisation's environment, have to consider the dynamic behaviour that is characteristic of macro-environments (as well as meso- and micro-environments). Consequently, the method should be adapted and automated as much as possible to capture real time changes in the environment and to reduce the workload [28]. However, both limitations can be improved in the future through experience with applying the developed approach to multiple and complex use cases and data sets.

Conclusions

Various political and legal efforts are being made at a global and EU level to reduce the use of fossil fuel resources in order to mitigate carbon emissions and to achieve a transition to a more sustainable society. In this context, a diversification and comprehensive modification of the energy mix and all industrial processes through the use of renewable alternatives is key. Establishing a sustainable circular bio-economy requires the successful introduction of innovative supply chain concepts, for instance those focusing on an increased utilisation of biogenic waste and residues, and the integration of green finance options. Stakeholders and policymakers need to be better equipped to support and accelerate the market uptake of innovations such as the ICC path examined in this study. Therefore, the expansion and integration of existing concepts, through the use of the PESTEL + I approach, should be considered to address the infrastructural aspects that seem to be especially important for bio-economy value chains. Putting an entire supply chain and its complex environment at the centre of an investigation better supports the work of strategy developers.

Applying the PESTEL + I method, which includes data collection, selection and analysis of the factors of the macro-environment of supply chains, remains labour-intensive. Consequently, future studies should be conducted on how to facilitate the procedure. For example, an automated digital tool such as a PESTEL + I database could be a good starting point to reduce research efforts. This may provide multiple users from research, industry, management and policy-making with an easy-to-use macro-environmental data tool to develop long-lasting and sustainable bio-economy value chains.

Abbreviations

CAQDAS	Computer assisted qualitative data analysis software
DBFZ	Deutsches Biomasseforschungszentrum gemeinnützige GmbH
EC	European Commission
EGD	European Green Deal
ESTEMPLE	Economic, social, technological, ecological, media, political, legal, ethical
ETPS	Economic, technological, political, social
EU	European Union
FPBO	Fast pyrolysis bio-oil
ICC	Intermediate carbon carrier
MUSIC	Market Uptake Support for Intermediate Bioenergy Carriers
P5F	Porter's Five Forces (analysis)
PEST	Political, economic, social, technological
PESTEL + I	Political, economic, social, technological, ecological, legal and infrastructural factors
REDII	Renewable Energy Directive II
RDT	Resource dependency theory
STEP	Social, technological, economic, political
STEPE	Social, technological, economic, political, ecological
STEEPLE	Social/demographic, technological, economic, environmental, political, legal, ethical
SH	Stakeholder
SWOT	Strengths, weaknesses, opportunities, threats
TOWS	SWOT backwards

Supplementary Information

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Additional file 1. Standard questions posed to upstream, conversion and downstream stakeholders. To collect primary data, semi-structured interviews with experts were held. The additional file gives an overview of possible questions that were posed to the interviewees. Not every one of the questions was posed to each interviewee, but it was carefully decided which questions suit best, depending on the individual background of the interviewee. The additional file is separated into three columns. While the first one contains questions that were posed to stakeholders from the upstream supply chain, those of the second column were posed to stakeholders with expertise on conversion aspects. The questions in the third column were posed to stakeholders from the downstream part of the supply chain.

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Availability of data and materials

Data generated or analysed during this study can be obtained from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.
Additional file 1.

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