Technology Analysis & Strategic Management

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ctas20

Actors' strategic goals in emerging technological innovation systems: evidence from the biorefinery sector in Germany

Lora Tsvetanova, Laura Carraresi, Michael Wustmans & Stefanie Bröring

To cite this article: Lora Tsvetanova, Laura Carraresi, Michael Wustmans & Stefanie Bröring (2021): Actors' strategic goals in emerging technological innovation systems: evidence from the biorefinery sector in Germany, Technology Analysis & Strategic Management, DOI: 10.1080/09537325.2021.1919300

To link to this article: https://doi.org/10.1080/09537325.2021.1919300

Published online: 11 May 2021.

TECHNOLOGY ANALYSIS & STRATEGIC MANAGEMENT
https://doi.org/10.1080/09537325.2021.1919300

Actors' strategic goals in emerging technological innovation systems: evidence from the biorefinery sector in Germany

Lora Tsvetanova [a], Laura Carraresi [b,c], Michael Wustmans [a] and Stefanie Bröring [a]

[a]Institute for Food and Resource Economics, Chair for Technology, Innovation Management and Entrepreneurship, University of Bonn, Bonn, Germany; [b]Faculty of Management Economics and Science, Lille Catholic University, Lille, France; [c]UMR 9221 LEM - Lille Économie Management, Lille, France

ABSTRACT

This paper explores the strategic goals behind actors' involvement in emerging technological innovation systems (TISs) for sustainable technologies and the way they contribute to the development of the TIS functions. Based on six expert interviews with firms within the biorefinery sector in Germany, we observe four different strategic goals driving firm-actors' involvement: (1) exploiting new markets and businesses, (2) learning about the potential of new markets and businesses, (3) developing new technologies and (4) building up new market applications. We also differentiate between three firm-actor types: (1) a leading type of incumbent firm highly contributing to the TIS functions; (2) a learning type of incumbent firm with lower contribution; and (3) a 'fill the gap' type of SME or start-up producing complementary knowledge or connecting other TIS actors.

ARTICLE HISTORY

Received 25 September 2020
Revised 17 February 2021
Accepted 2 April 2021

KEYWORDS

Technological innovation systems; strategic goals; actor typology; biorefinery sector

1. Introduction

Sustainability transitions demand cooperation between a wide range of private and public actors, whereby each actor contributes with unique strategic resources (Hilgartner 2007). One way to better frame and analyse such socio-technical evolutions is through the perspective of technological innovation systems (TISs) (Negro, Alkemade, and Hekkert 2012; Jacobsson and Bergek 2004, 2011). Indeed, the TIS literature has identified seven key functions that must be fulfilled to enable the generation, diffusion and utilisation of new technologies (Hekkert et al. 2007; Bergek, Hekkert, and Jacobsson 2008; Bergek, Jacobsson, et al. 2008): knowledge development, knowledge diffusion, entrepreneurial experimentation, influence on the direction of search, resource mobilisation, market formation, and legitimation.

This functional perspective is a suitable approach to describe or compare drivers and barriers for the deployment of new technologies. However, it cannot fully grasp the activities of innovating actors in the process, such as firms along the value chain, universities, governmental bodies, industry associations, NGOs, individual entrepreneurs, and users. To the best of our knowledge, little has been done to systematically explore the link between these actors and the TIS. It is not surprising, therefore, that researchers call for more attention on how the different actors' goals, resources, or capabilities impact the overall TIS (Markard and Truffer 2008; Farla et al. 2012; Musiolik, Markard, and Hekkert 2012; Musiolik et al. 2020). The way that different kinds of actors contribute to the development of a TIS is of particular importance in the case of emerging sustainable innovations, as it is

CONTACT Lora Tsvetanova l.tsvetanova@ilr.uni-bonn.de Institute for Food and Resource Economics, Chair for Technology, Innovation Management and Entrepreneurship, University of Bonn, Meckenheimer Allee 174, Bonn 53115, Germany

exactly actors' long term goals and visions that are supposed to guide the transitions (Berkhout 2006; Farla et al. 2012).

Therefore, the main objective of this exploratory empirical study is to identify relevant actors within the boundaries of an emerging and sustainability-oriented TIS, and to elucidate their contribution to the technology development process. More specifically, we conduct an actor-based analysis and explore:

> **RQ 1**: What are the strategic goals that actors follow when they decide to enter an emerging TIS in the domain of sustainable technologies?
>
> **RQ 2**: How can these actors be classified based on the strategic goals they follow?
>
> **RQ 3**: How do actors with different strategic goals contribute to the development of an emerging TIS in the domain of sustainable technologies?

To answer the research questions, we built an exploratory case study within the emerging biorefinery TIS in Germany and we focused on a particular type of actors, namely firms. Biorefineries are facilities that integrate biomass conversion processes to produce a spectrum of bio-based products (food/feed ingredients, chemicals, plastics) and bioenergy (biofuels, power, heat). They are considered an important pathway to address the challenges of climate change by reducing the demand for fossil resources (Bauer et al. 2017; Giurca and Späth 2017). Germany has a strong ambition to develop a bio-based economy by 2030 and efficient, yet sustainable biorefineries would be essential for the completion of this mission. At the same time, the successful development of a biorefinery TIS requires a joint effort from governments, researchers, and businesses, but the latter still struggle to drive the innovation process.

The contribution of this study is threefold: (1) From a theoretical viewpoint, it addresses the existing research gap in actors' impact on the development of a TIS (Markard and Truffer 2008; Farla et al. 2012; Musiolik et al. 2020). (2) From a methodological perspective, our study presents a bottom-up actor-based approach, rather than the established top-down analysis of functions (Hekkert et al. 2007; Bergek, Hekkert, and Jacobsson 2008; Bergek, Jacobsson, et al. 2008). (3) From a practical point of view, our findings offer a classification of actors based on similar strategic goals, that can be used to highlight the difference between the emerging focal system and the needed TIS configuration.

2. Conceptual and theoretical foundation

2.1. Technological innovation system (TIS)

The innovation system concept features a broad family of frameworks – national (Lundvall et al. 2002), regional (Cooke, Uranga, and Etxebarria 1997), sectoral (Malerba 2002; Fassio 2015), or technological (Carlsson and Stankiewicz 1991). As this study is focused on a particular technology field, we chose the technological innovation system (TIS) as our analytical framework. The TIS perspective regards technological change as a process of actions and interactions among a diverse set of actors engaged in generation, diffusion and utilisation of technologies (Carlsson and Stankiewicz 1991; Hekkert et al. 2007; Bergek, Jacobsson, et al. 2008). Actors can be firms along the value chain, universities, governmental bodies, industry associations, NGOs, individual entrepreneurs, and users – all engaged with activities related to the technology in focus. Through trade, cooperation or lobbying, actors develop networks, where they exchange knowledge, beliefs, and visions. Institutions are then the regulations, norms, and routines that guide the behaviour of actors.

Seven key processes, the so-called system functions, need to be in place for a TIS to perform well (Jacobsson and Bergek 2004; Hekkert et al. 2007; Bergek, Hekkert, and Jacobsson 2008). Knowledge development (F1) depicts the breadth and the depth of the knowledge base, and is a crucial function together with the diffusion of knowledge in the system (F2). Influence on the direction of search (F3) determines the selection or rejection of a particular trajectory of technological development.

Entrepreneurial experimentation (F4) refers to the exploring and exploiting of business opportunities based on new technologies and applications. And the last three functions relate to the formation of markets (F5), the extent of resource mobilisation (F6), and the ability to create legitimacy for the new technology (F7).

The TIS framework has been used to analyse innovation in the transition towards sustainability (Jacobsson and Bergek 2004; Negro and Hekkert 2008; Normann and Hanson 2018) and biorefinery technologies in particular (Hellsmark et al. 2016; Bauer et al. 2017; Giurca and Späth 2017; Hedeler et al. 2020). These studies focused primarily on forest-based biorefinery concepts and on functional analysis at the system level by assessing the strengths and weaknesses of the individual functions. However, less attention was given to actor-based analyses that examine the way actors from academia, governments, industry, and civil society create value for innovation systems (Hasche, Höglund, and Linton 2020).

2.2. Actor-based analysis in the TIS literature

Actors have a key role in TIS studies, where particular importance for the TIS development is ascribed to entrepreneurs, first-movers, or system builders (Negro, Hekkert, and Smits 2007; Musiolik and Markard 2011; Hansen and Coenen 2017; Jansma, Gosselt, and Jong 2018; Musiolik et al. 2020). Their strategic decisions affect the formation of different structures in the TIS (Farla et al. 2012; Markard and Truffer 2008; Musiolik et al. 2020). In some cases, relevant actors set goals and strategies that focus on one structural aspect of the TIS (e.g. development of technological knowledge) and give less importance to the other (e.g. non-technological knowledge and system building) (Hedeler et al. 2020). Such an imbalance can position the focal innovation in the proverbial 'valley of death'. But in other contrasting cases, actors forge networks, form a collective strategy, and actively shape the TIS, creating system resources such as common standards, support programmes, shared expectations (Musiolik et al. 2020).

This issue becomes even more intriguing when focussing specifically on firm-actors from different industries. Explanations of why firms commit themselves to the development of a new technology and how they organise their innovation activities in order to shape the new TIS are still partial (Markard and Truffer 2008; Musiolik and Markard 2011; Musiolik et al. 2020).

Furthermore, technologies that foster the transition towards a sustainable bio-based economy can be the focal point of many early stage TISs. Major characteristics of an emerging TIS are the high level of uncertainty regarding the technology categories that may become the dominant design, price/performance of the developed products, and the potential market volume (Berg, Wustmans, and Bröring 2019; Markard 2020). Given these potential risks, we assume that firm-actors would decide to enter an emerging TIS for sustainable technologies only if there is a consistent strategic fit.

Markard and Truffer (2008) propose an operationalisation of these goals along the following three types – leading, learning, and profile shaping. Actors who emphasise on achieving a prominent position in the new markets and allocate a high amount of resources to their innovation activity, are assigned to a leading strategy. If the firm's main aim is to gather experience and new knowledge while allocating a medium amount of resources, this is classified as a learning strategy. Finally, a profile shaping strategy is characterised by a low level of allocated resources and the aim to improve the corporate image. These actors' characteristics can be linked to the development of the TIS: different types of actors contribute to the different TIS functions and, in this way, impact the future evolution of the system. As this typology was derived from a case of sustainability-oriented innovation, we chose it as an appropriate basis for our study.

3. Method

To explore the roles of different actors in emerging, sustainability-oriented TISs, this study adopts a theory-building approach (Glaser, Strauss, and Strutzel 1968). The use of a case study method seems appropriate due to the exploratory nature of this research and its practicality in answering 'how' or 'why' questions when there is little empirical evidence available (Eisenhardt and Graebner 2007; Yin 2014). A combination of primary and secondary data sources was used. Data from patents and projects allowed to identify the relevant actors in the German biorefinery TIS. Semi-structured interviews with representatives of the main firm-actors aimed to explore what strategies these actors follow and how they contribute to the development of the TIS.

The focus of the paper is on Germany, being a leading economy in the EU, but also a country that made commitments to develop new technological solutions in support of the Bioeconomy (BMBF 2012, 2020). As the focal technology within the TIS, we selected the lignocellulosic biorefinery (henceforth LB). The LBs arose as an answer to the 'food vs. fuel' debate, avoiding direct competition with corn and edible vegetable oils. As illustrated on Figure 1. LBs utilise lignocellulosic biomass from the agricultural and forestry sectors (wood, agricultural residues or dedicated non-food plants), convert this feedstock into intermediate products (cellulose, hemicellulose, and lignin) which are then used for the formulation of final products such as biofuels, biochemicals, or biomaterials (Holladay et al. 2007; Cherubini and Strømman 2011; BMBF 2012). The study covers the period from 2010 to 2019, as in 2010 the first LB concept that could utilise all parts of the lignocellulosic feedstock material appeared (Michels and Wagemann 2010).

A pre-study based on secondary data aimed at identifying relevant firm-actors in the German LB TIS; six of these firms were then interviewed during the main study and the obtained qualitative data were analysed with regards to actors' strategic goals, types, and contribution to the TIS.

3.1. Pre-study: secondary data and definition of the TIS

To compile a list of relevant actors, a patent search was conducted via Derwent Innovation[1] on three different types of key technologies: pre-treatment of lignocellulosic biomass, production of lignocellulosic ethanol and production of lignin-based products. For this step, we looked at patents granted in Europe or specifically in Germany. Companies that appeared as patent assignees were included in the list.

Secondly, we used the Bio-based Industries Joint Undertaking (BBIJU) database,[2] as well as the EU-supported CORDIS[3] to compile a list of R&D projects that aimed to develop technologies for the utilisation of lignocellulosic biomass. We scanned all BBIJU projects under the classification VC1 – lignocellulose (19 projects in total). For the CORDIS database, we used 'lignocellulosic

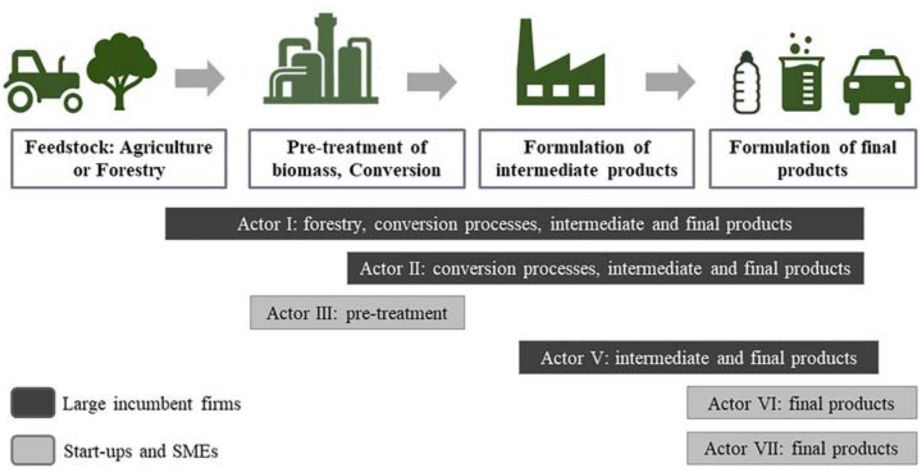

Figure 1. Interview partners positioned within the German lignocellulosic biorefinery value chain. Source: authors.

biomass' and 'lignocellulosic biorefinery' as search terms to retrieve relevant information. German companies that take an active role in these projects were included in the list.

By combining patent and project data we identified a total of 37 firms that contribute to the development of the TIS. Yet, the goal of this exploratory study was to elucidate companies that cover different activities along the LB value chain: biomass supply and logistics, conversion processes, or formulation of intermediate and final products (Figure 1). To appropriately illustrate the cross-sectoral nature of the LB TIS, we also needed to ensure that our final data sample consisted of firm-actors from different sectors. We approached representatives of firms that fit these criteria and invited them to take part in expert interviews. A total of seven individuals were interviewed between January 2019 and January 2020.

3.2. Main study: primary data collection and analysis

To collect information on companies' activities, goals, and strategic motivation, we sought to interview company founders, R&D managers and heads of departments related to sustainability-oriented innovation. As indicated in Figure 1 and Table 1, six of the seven interview partners represented companies covering different value chain steps and from industry sectors that are relevant for the development of the German LB TIS: the forest-based sector, bio-based materials, the chemical sector. The seventh interviewee was a member of a German association of chemistry and biotechnology and provided us with feedback on our interview guideline, with information on the overall development of the German LB TIS and, when possible, with commentary on the strategic behaviour of the other interviewed actors. Although six cases are in no way an exhaustive list of actors, in the context of exploratory research they can be considered as sufficient to illustrate the different types of pioneering firms that entered the German LB TIS. The interviews lasted between 21 and 56 min and were conducted via phone or video chat software. The interviews were then recorded, transcribed, and analysed with the coding software MAXQDA.[4] For this task, a code book was created through a mixture of inductive and deductive method. The deductive codes were based on Markard and Truffer`s categories for strategy-oriented actor analysis, as well as existing literature on indicators for mapping the development of TIS functions (Hekkert et al. 2007; Markard and Truffer 2008; Bergek, Hekkert, and Jacobsson 2008; Bergek, Jacobsson, et al. 2008). Emerging codes were developed with respect to the actors' goals and motivation.

The analysis was conducted with data from the six firm cases – Actors 1, 2, 3, 5, 6 and 7, as described in Table 1. The remaining Actor 4 represented a large professional network. As such, they could not be analysed as a firm-actor with individual activities, goals and strategic motivation and were therefore not included in the cross-case comparison. Nevertheless, Actor 4 was treated as a general informant with insights on the development of biorefinery technologies in Germany.

4. Results

4.1. Actors' strategic goals

We identified four strategic goals: (1) exploiting new markets and businesses, (2) learning about the potential of new markets and businesses, (3) developing new technologies and (4) building up new market applications.

4.1.1. Exploiting new markets and businesses

Two companies in the empirical sample entered the German LB TIS with the intention to exploit business opportunities. Actor 1 is planning to enter the German LB TIS by building a commercial scale biorefinery in the country. The company is a leader in the pulp and paper sector and, after realising the decline of its main product, started experimenting the revitalisation of the product with biorefining technologies.

Table 1. Cross case comparison regarding actors' goals, activities, and priority given to LB.

	Incumbent firms			Start-ups and SMEs		
	Actor 1	Actor 2	Actor 5	Actor 3	Actor 6	Actor 7
Interview partner	Director Lignin Businesses	Head of Development and Biomanufacturing	Head of Sustainable Businesses	Founder and CEO	Founder and CTO	R&D and Project Manager
Sector	Pulp and paper, biomaterials, and bio-chemicals	Chemicals	Chemicals	Specialized consultancy	Bio-based materials from lignin	Bio-based materials
Company type	Established corporation	Established corporation	Established corporation	SME, founded by academic researcher	Start-up, university spin-off	SME, university spin-off
Relevance to the German LB TIS	Currently planning to build a LB	Pre-commercial LB, technology licensing	Active on markets for biorefinery products	Expert in LB conversion methods	Active on markets for biorefinery products	Active on markets for biorefinery products
Goals	Goal 1: Exploit new markets and businesses from an abundant renewable resource. Contribute to an economy that is not dependent on fossil.	Goal 1: Exploit new markets and businesses from an abundant renewable resource. Develop a technically and economically efficient LB.	Goal 2: Learn about the potential of LB and related products.	Goal 3: Develop a sustainable and efficient technologies for LB pre-treatment and conversion.	Goal 4: Build up markets and applications for LB-derived lignin. Replace fossil sources with an affordable, bio-based and biodegradable solution.	Goal 4: Build up markets and applications for LB products (lignin). Substitute fossil-based materials with bio-based.
Activities	Broad portfolio of LB-related activities.	Broad portfolio of LB-related activities.	Focus on economic evaluation of a LB.	Focus on alternative biomass processing technologies.	Focus on lignin and its applications.	Focus on bio-based raw materials and their application in plastics.
Priority given to LB	High: biorefineries are a separate business area.	High: advanced biofuels are a separate business area.	Medium to Low	High: biorefining technologies is a main expert area.	High: developing product applications from lignin is sole activity.	Medium to High: lignin products are one of 3 product families.
Suggested actor type	The leading type	The leading type	The learning type	The 'fill the gap' type	The 'fill the gap' type	The 'fill the gap' type

Source: authors.

Actor 2, on the other hand, developed its own processing technology to turn agricultural residues into cost competitive lignocellulosic ethanol. After successful demonstration in its pilot plant in Germany, the company is both licensing the processing technology to other actors and building a full commercial scale biorefinery in Eastern Europe.

4.1.2. Learning about the potential of new markets and businesses

In contrast to the first two actors, Actor 5 is no longer an active participant in LB innovation. The company was involved in a publicly funded R&D project for a LB pilot plant with the task to evaluate the economic feasibility of a biorefinery.

> Our part at the time was in fact to look at the economics, at the business case for the whole topic (…) the biggest challenge was to find an application for the lignin except for burning it. (Interview partner 5)

Based on this information, we assigned Actor 5 to the goal 'learn about the potential of new markets and businesses' as they were not engaged in the actual development of technologies or applications.

4.1.3. Developing new technologies

The entrepreneurial Actor 3 is engaged in developing pre-treatment and technologies for lignocellulosic biomass. This informant is still actively collaborating with universities and research institutes, developing new technologies that can be tailored to different biomass sources (e.g. softwood trees, designated perennial plants, agricultural waste).

4.1.4. Building up new applications

Last but not least, the firms that we labelled as Actor 6 and Actor 7 entered the German LB TIS with the goal to develop new market applications. They were both German SMEs and university spin-offs with a strong focus on bio-based materials. Actor 6 aimed at identifying valuable applications for various types of lignin:

> It all started with a biorefinery project at the university (…). Soon we discovered that other applications [for the lignin] were possible, particularly for cosmetics and food. We saw interest from the industry but companies [biorefineries, lignin producers] did not know where to start innovating with lignin. We realized that a lot of pulp and paper producers just burn their lignin and so, we decided to provide a link between the two. (Interview partner 6)

And Actor 7 approached the biorefinery-derived products with a particular application, namely composite materials with thermoplastic properties:

> Our managing directors were involved in several projects where lignin was the focus – to find a material which could be based on lignin and could have a thermoplastic behaviour. (Interview partner 7)

4.2. Actor types

Following Markard and Truffer (2008), we derived deductive codes for the scope of LB activities that the actor engages with and the priority that LB projects receive within the companies. In the course of the analysis, we observed differences in the strategic goals and scope of activities of the different actors that could have been explained with the size of the companies: large established corporations aimed at achieving a prominent position within the LB sector, while smaller start-ups and SMEs strived to excel in specific niches. In order to compare and assess these actors in a fair manner, we divided them in two groups – incumbents and Start-ups/SMEs. Table 2 summarises the results of this classification.

4.2.1. Typology and activities of incumbents

Actors 1, 2 and 5 all represent companies that already had a position on a relevant market before engaging with LB-related activities. Within this group, we identified two different types – the leading and the learning type.

The Leading Type: for two companies in the sample (Actor 1 and Actor 2), the development of new markets and businesses from an abundant renewable resource was stated as a strategic goal. A high priority was given to LB-related projects as they played a big part of the public relation activities of the two firms. Both Actor 1 and Actor 2 engaged in a broad range of activities from patenting own technologies to building commercial scale LB plants: Actor 1 plans to build it in Germany, closer to raw materials but also to big markets (of chemicals in this case), while Actor 2 demonstrated the feasibility of their process in a plant in Germany, but is currently building a commercial scale facility in eastern Europe, closer to a more cost efficient raw material (particularly straw) and operating on the cost competitive market of biofuels. These companies can both be classified as actors following a

Table 2. Strategic types and their contribution to the TIS.

	Incumbent firms			Start-ups and SMEs		
	The leading type		The learning type	The 'fill the gap' type		
Function	Actor 1	Actor 2	Actor 5	Actor 3	Actor 6	Actor 7
F1	Develops knowledge and patents in the field of processing technologies and lignin applications.	Develops knowledge and patents in the field of processing technologies and biofuels.	Developed knowledge on a particular business case and outlined potential issues.	Develops knowledge and patents in the field of biomass pre-treatment.	Develops knowledge and patents in the field of lignin applications.	
F2	Involved in research projects.	Involved in research projects Licenses its main LB technology.	Involved in research projects.	Involved in research projects with different stakeholders.		
F3	Mainly a policy-driven function but A1 and A2 articulate positive expectations of growth potential with their investments.		Does not contribute to the development of F3.	Articulate interest and growth potential. Their markets are still rather niche.		
F4	Incumbent actors that diversify their activities. Create new opportunities and business venture.		Incumbent actor. Limited contribution to F4 as only learning activities were conducted.	Entrepreneurial actors. Contribute to a high degree of variety in the processing technology and the final product applications.		
F5	Supports markets for biochemicals and biomaterials.	Focuses on fuels.	Evaluated the market potential of biomaterials but did not develop products.	Contribute to the formation of markets for biomaterials and bio-chemicals. Actors 6 and 7 link producers and users of LB-derived products.		
F6	Contribute through capital investments and infrastructural assets (biorefinery plants).		Does not contribute to the development of F6.	Contribute to the creation of complementary knowledge.		
F7	Publicly expressing a positive attitude towards the future and purpose of LB technologies.		Skeptical towards the economic feasibility and potential of large-scale production.	Publicly expressing a positive attitude towards the future and purpose of LB technologies.		

Source: authors. TIS functions as defined by Bergek, Hekkert, and Jacobsson (2008); Jacobsson and Bergek (2011).

leading strategy, with the potential to shape the future development of the TIS by demonstrating economically feasible processes.

The Learning Type: Actor 5 took part in a LB-related project based on the goal to acquire knowledge on the business potential of LBs. Medium to Low priority was given to LB activities and mostly human resources were invested. We can classify this company as an actor following a learning strategy. As the final project results did not prove an attractive business case, the company lost interest and exited the TIS. This finding suggests that actors following a strategy characterised by lower priority, less invested resources, and no strong motivation to build new markets are more likely to exit the emerging TIS in times of uncertainty.

> Those topics that are closer to raw materials are not in the focus any longer. Potentially, if these processes are developed it would only be a sourcing topic for us because strategy-wise currently we are not looking into any backward integration. (Interview partner 5)

4.2.2. Typology and activities of start-ups and SMEs

The Fill the Gap Type: This actor type was not identified in the study of Markard and Truffer (2008) and, therefore, represents the main contribution of this paper. The type refers to Actors 3, 6 and 7, which can all be classified as Start-ups or SMEs. Additionally, all three have a connection to the academic field. LB-related activities hold a high priority in all three cases. For Actor 3 the development of alternative biomass processing technologies (lower environmental impact, higher quality of the derived products) is a main activity; for Actor 6 the development of product applications for different types of lignin is the core business; in the case of Actor 7, lignin-based materials are one of the three product families that the company offers. The scope of their LB-related activities was narrower than the scope of the actors following a leading strategy. It must be noted, however, that these Actors operate and aim to excel in niches where complementary knowledge is missing. This is especially true for Actor 6 and Actor 7 where the respective interview partners describe their activities as 'linking the producers of lignin to the material industry' (Interview partner 6) and their main contributions to the development of LB projects as

> It is the knowledge about the material and the development of the final lignin-based material. And this is what we do – we do the testing of different lignins and investigate how they influence the properties of the final material (Interview partner 7).

The Profile Shaping Type: although featured in the original work of Markard and Truffer (2008), we could not identify a representative of the profile shaping actor type in our sample. These companies would assign a low priority to LB projects and will engage in these to appear more innovative or more sustainability-oriented. The lack of profile shaping actors in the sample can be explained by nature of our focal technology: biorefineries are a process innovation and as such require considerable investments in facilities, and infrastructure. At the same time, they face the risk of uncertain market conditions. If a company does not find the business case appealing, they would leave the sector, similarly to Actor 5, rather than engage in a profile shaping behaviour. Another possible explanation is the limited number of interview partners and the so called 'participation bias': the interview partners who agreed to participate in our study were the ones who were truly invested in LB technologies to begin with.

4.3. Actors' contribution to the development of the TIS

In order to assess how different types of actors with their different strategic goals contribute to the development of the TIS, we looked into their activities and impact on the TIS functions. Contrary to Markard and Truffer's (2008) who linked activities to functions in a rather interpretational manner, in this study we based our coding procedure on the indicators that map the development of TIS functions (as defined by Bergek, Hekkert, and Jacobsson 2008; Jacobsson and Bergek 2011). For example, the market for biofuels has already been successfully formed due to policy incentives and quotas

(Bauer et al. 2017). In the meantime, 'number, size and type of successfully formed markets' is an indicator for the status of the function market formation. And therefore, if an actor is present on an alternative market (e.g. bio-based chemicals or materials), we would regard them as positively contributing to the development of the function market formation (F5).

The results are depicted in Table 2 and can be interpreted as follows: all interviewed companies contribute to the development the LB TIS functions except for Actor 5 as they are no longer active in the field. The other two incumbents (Actors 1 and 2) articulate positive expectations for the development of LBs by building actual facilities on a commercial scale. In that way they contribute not only to entrepreneurial experimentation (F4) and legitimation of the biorefinery concept in the public eye (F7), but also to the direction of search (F3) by providing incentives for actors to enter the TIS (e.g. actors that would be suppliers for these biorefineries). Following the strategic aim to develop new markets and businesses around LB technologies, Actor 1 and Actor 2 invest in infrastructural assets and thus positively impact the function resource mobilisation (F6).

Actors 3, 6 and 7, on the other hand, strengthen the development of new technologies and market applications, thus mainly contributing to the function entrepreneurial experimentation (F4). Their major contribution to the German LB TIS, however, is the links they build between other important actors. One could attribute this activity to the formation of new markets (F5), but also to resource mobilisation (F6), as far as complementary knowledge can be considered a resource needed in an emerging and complex TIS.

5. Discussion and conclusion

The presented empirical study illustrated an actor-based analysis within the context of an emerging sustainability-oriented TIS. Within our study, we identified four general goals that drive the decision to enter an emerging sustainability-oriented TIS, namely (1) exploiting new markets and businesses, (2) learning about the potential of new markets and businesses, (3) developing new technologies and (4) building up new market applications. With this finding, we contribute to the ongoing discussion on biorefinery TIS (Bauer et al. 2017; Giurca and Späth 2017) by demonstrating that industry actors can be classified by industry sector, but also as developers of new businesses, of new technology variations, and new applications. In a broader sense, such an approach may prove useful in assessing the actual and the needed structural configuration of a TIS – a lack of business developers, for example, would have constituted a significant barrier for the future development of the TIS. This could be particularly true for sustainability-oriented TISs, as the initial stages of these technologies are often characterised with economic inefficiency and uncertainty that does not attract industry participation.

To answer the second research question, we classified the actors in our sample into three types, based on strategic goals, activities within the TIS, and priority of the focal innovation within the company. Similar to the results of Markard and Truffer (2008), we found patterns of leading and learning actor types among the incumbents, yet a profile shaping actor type was not present in the selected sample. We could, however, identify a new type of actors – the 'fill the gap' actor that is a SME or a start-up and can create complementary knowledge or link other TIS actors. This finding complements the study of Bauer et al. (2017) stating that opportunities for SMEs exist in the biorefinery field, but the exact nature of their activities is unknown (Bauer et al. 2017). Notably, all 3 'fill the gap' actors within our sample had a strong connection to academia (university spin-offs or entrepreneurial scientists), thus highlighting once again the importance of technology transfer from academia to industry in the interdisciplinary bio-based economy (Borge and Bröring 2017).

Lastly, our third research question called for an assessment of the different actor types and the way they contribute to the development of an emerging sustainability-oriented TIS. We observed that the leading type of actors contributed the strongest to the development of TIS functions, which is again in line with what Markard and Truffer (2008) detected. It can be expected that the two leading actors (Actors 1 and 2) will impact the future development of LBs in Germany. This finding demonstrates once again that incumbent firms are able to introduce change into their mature sectors and bring disruptive innovation (Kishna et al. 2017). Moreover, these two actors illustrate the notion of organisational ambidexterity, as they exploit their traditional businesses but at the same time develop capabilities necessary for exploring a new technological domain (O'Reilly and Tushman 2013). Another type of actor, the 'fill the gap' type, contributes to entrepreneurial experimentation by creating a variety in technologies and market applications. This is a rather important role as variability in a TIS can lead to a steady growth process, formation of multiple market segments, and a broad knowledge base that fosters the development of new scientific concepts (Dewald and Truffer 2011). For technologies that rely on biomass, this can mean a more sustainable, efficient use of all plant parts, waste streams, and by-products. On the other hand, such variability in technologies and applications can bring transformations on a value chain level requiring new linkages or a complete redesign (Carraresi, Berg, and Bröring 2018; Carraresi and Bröring 2021). While they can be regarded as orchestrators within the TIS value chain (Schweizer 2005; Carraresi and Bröring 2021) the existence of 'fill the gap' actors can be an indication of strategic system building activities in the 'partner mode', where suppliers and manufacturers integrate complementary resources to co-create products and markets (Musiolik et al. 2020).

This study contributes to the TIS literature by expanding the knowledge of TIS actors and their activities. We verify Markard and Truffer's (2008) approach in exploring the impact of actors and their activities on systems' functions. Furthermore, we extend Markard and Truffer's (2008) typology of actors by identifying a new type- the 'fill the gap' actors. From a managerial perspective, taking part in an emerging TIS for sustainable technologies is a challenge, especially when the innovative concept draws knowledge from several domains and industry sectors. Our approach can assist firms in identifying the 'fill the gap' actors that can link them to external knowledge, resources or even markets, thus improving their level of absorptive capacity (Cohen and Levinthal 1990). Lastly, policy makers may address TIS weaknesses and blocking mechanisms more explicitly based on an actor-oriented analysis. For example, in TIS without a clear leading actor, incentivizing 'fill the gap' type of actors to connect small firms with complementary assets could be a possible solution.

Our study, however, faces a few limitations. The first one is derived from the fact that we focused on one particular type of TIS actors, namely firms along the LB value chain. The second one is related to the nature of the case method itself, as a degree of subjectivity remains when analysing the interview data. Furthermore, the findings are drawn from a small and incomplete list of interview partners, and generalisations need to be done with caution. Lastly, the LB TIS is only one example of an emerging, sustainability-oriented TIS. To overcome the limitations of our approach, future research can focus on different TIS actors such as biomass suppliers or consumers of bio-based products, which in the context of a sustainability-oriented TIS can be businesses, citizens or even society as a whole (Hasche, Höglund, and Linton 2020). Furthermore, scholars could expand the applicability of the actor typology by analysing other TISs and by including cases from leading, as well as from developing countries.

Notes

1. Available at https://clarivate.com/products/derwent-innovation/, last accessed on 19.05.2019.
2. Available at https://bbi-europe.eu/, last accessed on 10.05.2019.
3. Available at https://cordis.europa.eu/en, last accessed on 10.05.2019.
4. Available at https://www.maxqda.com/ last accessed 01.03.2020.

Acknowledgements

This paper is carried out within the framework of the project 'Advanced Pulping for Perennial Plants: A holistic and sustainable integrated lignocellulose biorefinery concept' (AP^3) of the Bioeconomy Science Centre (BioSC). For further information, please refer to https://www.biosc.de/AP3_en. The scientific activities of the Bioeconomy Science Centre were financially supported by the Ministry of Innovation, Science and Research of the German State of North Rhine-Westphalia within the framework of the NRW Strategieprojekt BioSC (No. 313/323-400-002 13).

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the Ministry of Innovation, Science and Research of the German State of North Rhine-Westphalia within the framework of the NRW Strategieprojekt BioSC [grant number No. 313/323-400-002 13].

Notes on Contributors

Lora Tsvetanova is a PhD student at the Chair of Technology, Innovation Management and Entrepreneurship, University of Bonn, Germany. She holds a master's degree in agricultural and food economics and a bachelor's degree in business administration. Her current research is into technological innovation systems, especially within the bioeconomy. She seeks to understand the role that organizational actors play in the development and diffusion of sustainable technologies.

Laura Carraresi is an associate professor at the Faculty of Management Economics and Science, Lille Catholic University, France. She obtained her PhD in innovation technology for agri-food and environmental sciences at the University of Milan, Italy, in 2009. Her research covers innovation management and sustainability transitions, as well as emerging value chains, and business model innovation.

Michael Wustmans is a Research Associate (Post-Doc) at the chair for Technology, Innovation Management and Entrepreneurship at the University of Bonn, Germany. There, he is leading the research group Technology Dynamics focusing on research topics related to technological change driven by sustainability transitions. He obtained his PhD at the University of Bremen, Germany, where he focused on patent intelligence for decision-making.

Stefanie Bröring is a professor of Technology, Innovation Management and Entrepreneurship at the Institute for Food and Resource Economics, University of Bonn, Germany. She obtained her PhD in business administration at the University of Münster, Germany in 2005. Her research covers the emergence of new technologies, technology convergence as well as science-based entrepreneurship in the field of sustainable technologies.

ORCID

Lora Tsvetanova http://orcid.org/0000-0002-8945-3561
Laura Carraresi http://orcid.org/0000-0003-0081-6651
Michael Wustmans http://orcid.org/0000-0002-0231-8560
Stefanie Bröring http://orcid.org/0000-0003-2014-2586

References

Bauer, Fredric, Lars Coenen, Teis Hansen, Kes McCormick, and Yuliya Voytenko Palgan. 2017. "Technological Innovation Systems for Biorefineries: A Review of the Literature." *Biofuels, Bioproducts and Biorefining* 11 (3): 534–548.

Berg, S., M. Wustmans, and S. Bröring. 2019. "Identifying First Signals of Emerging Dominance in a Technological Innovation System: A Novel Approach Based on Patents." *Technological Forecasting and Social Change* 146: 706–722.

Bergek, Anna, Marko Hekkert, and Staffan Jacobsson. 2008. "Functions in Innovation Systems: A Framework for Analysing Energy System Dynamics and Identifying Goals for System-Building Activities by Entrepreneurs and Policy Makers." In *Innovation for a low Carbon Economy: Economic, Institutional and Management Approaches*, edited by T. Foxon, J. Kohler, and C. Oughton, 79. Cheltenham: Edward Elgar.

Bergek, Anna, Staffan Jacobsson, Bo Carlsson, Sven Lindmark, and Annika Rickne. 2008. "Analyzing the Functional Dynamics of Technological Innovation Systems: A Scheme of Analysis." *Research Policy* 37 (3): 407–429.

Berkhout, Frans. 2006. "Normative Expectations in Systems Innovation." *Technology Analysis & Strategic Management* 18 (3-4): 299–311.

BMBF. 2012. Biorefineries Roadmap: As Part of the German Federal Government Action Plans for the Material and Energetic Utilisation of Renewable Raw Materials. Berlin. https://www.bmbf.de/upload_filestore/pub/Roadmap_Biorefineries_eng.pdf.

BMBF. 2020. Bioökonomie – Biogene Ressourcen und Biologisches Wissen für eine nachhaltige Wirtschaft. With assistance of BMEL. Berlin. https://ec.europa.eu/knowledge4policy/publication/german-national-bioeconomy-strategy_en, checked on 5/7/2020.

Borge, Laura, and Stefanie Bröring. 2017. "Exploring Effectiveness of Technology Transfer in Interdisciplinary Settings: The Case of the Bioeconomy." *Creativity and Innovation Management* 26 (3): 311–322.

Carlsson, Benny, and Rikard Stankiewicz. 1991. "On the Nature, Function and Composition of Technological Systems." *Journal of Evolutionary Economics* 1 (2): 93–118.

Carraresi, Laura, Silvan Berg, and Stefanie Bröring. 2018. "Emerging Value Chains Within the Bioeconomy: Structural Changes in the Case of Phosphate Recovery." *Journal of Cleaner Production* 183: 87–101.

Carraresi, Laura, and Stefanie Bröring. 2021. "How Does Business Model Redesign Foster Resilience in Emerging Circular Value Chains?" *Journal of Cleaner Production* 289: 125823.

Cherubini, Francesco, and Anders H. Strømman. 2011. "Chemicals from Lignocellulosic Biomass: Opportunities, Perspectives, and Potential of Biorefinery Systems." *Biofuels, Bioproducts and Biorefining* 5 (5): 548–561.

Cohen, Wesley M., and Daniel A Levinthal. 1990. "Absorptive Capacity: A New Perspective on Learning and Innovation." *Administrative Science Quarterly* 35: 128–152.

Cooke, Philip, Mikel Gomez Uranga, and Goio Etxebarria. 1997. "Regional Innovation Systems: Institutional and Organisational Dimensions." *Research Policy* 26 (4-5): 475–491.

Dewald, Ulrich, and Bernhard Truffer. 2011. "Market Formation in Technological Innovation Systems—Diffusion of Photovoltaic Applications in Germany." *Industry and Innovation* 18 (03): 285–300.

Eisenhardt, Kathleen M., and Melissa E Graebner. 2007. "Theory Building from Cases: Opportunities and Challenges." *Academy of Management Journal* 50 (1): 25–32.

Farla, Jacco, Jochen Markard, Rob Raven, and Lars Coenen. 2012. "Sustainability Transitions in the Making: A Closer Look at Actors, Strategies and Resources." *Technological Forecasting and Social Change* 79 (6): 991–998.

Fassio, Claudio. 2015. "How Similar is Innovation in German, Italian and Spanish Medium-Technology Sectors? Implications for the Sectoral Systems of Innovation and Distance-to-the-Frontier Perspectives." *Industry and Innovation* 22 (2): 102–125.

Giurca, Alexandru, and Philipp Späth. 2017. "A Forest-Based Bioeconomy for Germany? Strengths, Weaknesses and Policy Options for Lignocellulosic Biorefineries." *Journal of Cleaner Production* 153: 51–62.

Glaser, Barney G., Anselm L. Strauss, and Elizabeth Strutzel. 1968. "The Discovery of Grounded Theory; Strategies for Qualitative Research." *Nursing Research* 17 (4): 364.

Hansen, Teis, and Lars Coenen. 2017. "Unpacking Resource Mobilisation by Incumbents for Biorefineries: The Role of Micro-Level Factors for Technological Innovation System Weaknesses." *Technology Analysis & Strategic Management* 29 (5): 500–513.

Hasche, Nina, Linda Höglund, and Gabriel Linton. 2020. "Quadruple Helix as a Network of Relationships: Creating Value Within a Swedish Regional Innovation System." *Journal of Small Business & Entrepreneurship* 32 (6): 523–544.

Hedeler, Barbara, Miriam Lettner, Tobias Stern, Peter Schwarzbauer, and Franziska Hesser. 2020. "Strategic Decisions on Knowledge Development and Diffusion at Pilot and Demonstration Projects: An Empirical Mapping of Actors, Projects and Strategies in the Case of Circular Forest Bioeconomy." *Forest Policy and Economics* 110: 102027.

Hekkert, Marko P., Roald A. A. Suurs, Simona O. Negro, Stefan Kuhlmann, and Ruud EHM Smits. 2007. "Functions of Innovation Systems: A New Approach for Analysing Technological Change." *Technological Forecasting and Social Change* 74 (4): 413–432.

Hellsmark, Hans, Johanna Mossberg, Patrik Söderholm, and Johan Frishammar. 2016. "Innovation System Strengths and Weaknesses in Progressing Sustainable Technology: The Case of Swedish Biorefinery Development." *Journal of Cleaner Production* 131: 702–715.

Hilgartner, Stephen. 2007. "Making the Bioeconomy Measurable: Politics of an Emerging Anticipatory Machinery." *BioSocieties* 2 (3): 382–386.

Holladay, John E., James F. White, Joseph J. Bozell, and David Johnson. 2007. *Top Value-Added Chemicals from Biomass-Volume II—Results of Screening for Potential Candidates from Biorefinery Lignin*. Richland, WA: Pacific Northwest National Lab. (PNNL).

Jacobsson, Staffan, and Anna Bergek. 2004. "Transforming the Energy Sector: The Evolution of Technological Systems in Renewable Energy Technology." *Industrial and Corporate Change* 13 (5): 815–849.

Jacobsson, Staffan, and Anna Bergek. 2011. "Innovation System Analyses and Sustainability Transitions: Contributions and Suggestions for Research." *Environmental Innovation and Societal Transitions* 1 (1): 41–57.

Jansma, Sikke R., Jordy F. Gosselt, and Menno D. T. de Jong. 2018. "Technological Start-ups in the Innovation System: An Actor-Oriented Perspective." *Technology Analysis & Strategic Management* 30 (3): 282–294.

Kishna, Maikel, Simona Negro, Floortje Alkemade, and Marko Hekkert. 2017. "Innovation at the end of the Life Cycle: Discontinuous Innovation Strategies by Incumbents." *Industry and Innovation* 24 (3): 263–279.

Lundvall, Bengt-Åke, Björn Johnson, Esben Sloth Andersen, and Bent Dalum. 2002. "National Systems of Production, Innovation and Competence Building." *Research Policy* 31 (2): 213–231.

Malerba, Franco. 2002. "Sectoral Systems of Innovation and Production." *Research Policy* 31 (2): 247–264.

Markard, Jochen. 2020. “The Life Cycle of Technological Innovation Systems.” *Technological Forecasting and Social Change* 153: 119407.
Markard, Jochen, and Bernhard Truffer. 2008. “Actor-oriented Analysis of Innovation Systems: Exploring Micro-Meso Level Linkages in the Case of Stationary Fuel Cells.” *Technology Analysis & Strategic Management* 20 (4): 443–464.
Michels, Jochen, and Kurt Wagemann. 2010. “The German Lignocellulose Feedstock Biorefinery Project.” *Biofuels, Bioproducts and Biorefining: Innovation for a Sustainable Economy* 4 (3): 263–267.
Musiolik, Jörg, and Jochen Markard. 2011. “Creating and Shaping Innovation Systems: Formal Networks in the Innovation System for Stationary Fuel Cells in Germany.” *Energy Policy* 39 (4): 1909–1922.
Musiolik, Jörg, Jochen Markard, and Marko Hekkert. 2012. “Networks and Network Resources in Technological Innovation Systems: Towards a Conceptual Framework for System Building.” *Technological Forecasting and Social Change* 79 (6): 1032–1048.
Musiolik, Jörg, Jochen Markard, Marko Hekkert, and Bettina Furrer. 2020. “Creating Innovation Systems: How Resource Constellations Affect the Strategies of System Builders.” *Technological Forecasting and Social Change* 153: 119209.
Negro, Simona O., Floortje Alkemade, and Marko P Hekkert. 2012. “Why Does Renewable Energy Diffuse so Slowly? A Review of Innovation System Problems.” *Renewable and Sustainable Energy Reviews* 16 (6): 3836–3846.
Negro, Simona O., and Marko P Hekkert. 2008. “Explaining the Success of Emerging Technologies by Innovation System Functioning: The Case of Biomass Digestion in Germany.” *Technology Analysis & Strategic Management* 20 (4): 465–482.
Negro, Simona O., Marko P. Hekkert, and Ruud E Smits. 2007. “Explaining the Failure of the Dutch Innovation System for Biomass Digestion—a Functional Analysis.” *Energy Policy* 35 (2): 925–938.
Normann, Håkon Endresen, and Jens Hanson. 2018. “The Role of Domestic Markets in International Technological Innovation Systems.” *Industry and Innovation* 25 (5): 482–504.
O’Reilly, Charles A., and Michael L Tushman. 2013. “Organizational Ambidexterity: Past, Present, and Future.” *Academy of Management Perspectives* 27 (4): 324–338.
Schweizer, Lars. 2005. “Concept and Evolution of Business Models.” *Journal of General Management* 31 (2): 37–56.
Yin, Robert K. 2014. *Case Study Research: Design and Methods*. 5th ed. Thousand Oaks, CA: Sage.