Innovative Food Science and Emerging Technologies 29 (2015) 308–317

Contents lists available at ScienceDirect

Innovative Food Science and Emerging Technologies

journal homepage: www.elsevier.com/locate/ifset

The emerging research landscape on bioeconomy: What has been done so far and what is essential from a technology and innovation management perspective?

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ARTICLE INFO

Article history:
Received 8 October 2014
Received in revised form 19 December 2014
Accepted 5 March 2015
Available online 21 March 2015

Keywords:
Bioeconomy
Publication analysis
Technology and innovation management

ABSTRACT

As the global resource base is in need to move from fossil towards bio-based raw materials, different supply chains as well as existing technology platforms become increasingly interconnected. The therefore needed creation and exchange of new knowledge across scientific disciplines require R&D and target technology development and innovation, linking the knowledge-based bioeconomy to technology and innovation management research. In order to get an overview of the current research landscape dealing with the bioeconomy, a publication analysis is conducted. As the number of empirical studies, particularly in management research, is low, our study reveals that the evolution of the bioeconomy is still on a strategic level. Existing studies focus on knowledge networks, open innovation and technologies applicable across value chains to enable a holistic view on organizing future resource allocation and biomass flows. Scientific research in several dimensions is needed to elaborate the bioeconomy concept to make its implementation manageable.

Industrial relevance: Value chains, particularly of the agri-food, industrial products and energy sector, will increasingly converge due to the shift to bio-based raw materials leading to a mutual dependence and triggering new material flows and food processing technologies. This paper suggests that essential innovation management related research frames might contribute to a sustainable evolution of the bioeconomy by addressing the major challenges.

Contents

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http://dx.doi.org/10.1016/j.ifset.2015.03.006
1466-8564/

1. Introduction

The concept of a knowledge-based bioeconomy (KBBE) has been introduced by the European Commission in 2004 (Albrecht et al., 2010). However, its importance has already been highlighted before e.g., by Hardy declaring that '*The bio-based economy can and should be to the 21st century what the fossil-based economy was to the 20th century.*' (Hardy, 2002, p.11). This statement emphasizes the outstanding relevance of the bioeconomy for both academia and industry, which is also characterized by an increase of funding in recent years, particularly within Europe (Staffas, Gustavsson, & McCormick, 2013). Current European research framework programs like 'HORIZON 2020' are aiming at promoting innovations within research areas of the evolving bioeconomy (Albrecht et al., 2010; BECOTEPS, 2011; Cichocka et al., 2011; European Commission, 2012). But although the second decade of the 21st century has already begun, the concept of bioeconomy still appears to be fuzzy. The necessity of a transition from a fossil- to a bio-based economy has been emphasized; nevertheless, existing publications mainly originate from governmental institutions and are primarily concerned with strategic agendas than with the identification of challenges and measures to implement the bioeconomy. Moreover, the need for an interdisciplinary view on bioeconomy-related research seems particularly evident for research dealing with novel technologies, e.g., to enable the usage of side streams (Vaneeckhaute, Meers, Michels, Buysse, & Tack, 2013). In this context, interdisciplinary research not only faces engineering and natural sciences-related challenges but also socioeconomic challenges such as societal expectations affecting the adoption of new bioeconomic products and processes. Hence, an integration of concepts and knowledge platforms from different disciplines is required to explore the prerequisites for implementing the bio-based economy.

What could this integration look like? As the widely-used acronym KBBE already implies, the 'knowledge-based bioeconomy' demands the creation, exchange and application of (new) knowledge to support a sustainable development. These knowledge management activities require R&D and are, if successful, leading to technologies and innovations. Here, the area of technology and innovation management (TIM) research comes into play. Belonging to the research domain of management, TIM research seeks to understand how novel technologies and innovations emerge and how they can be commercialized successfully. The therewith associated research frames tackling questions such as 'from mind to market' (Afuah, 2003) seem particularly important in order to understand how to move towards the, yet, mainly technology-driven evolution of the bioeconomy. In view of the above, we conduct a meta-analysis on the emerging research landscape dealing with bioeconomy to answer the following research questions (RQ) regarding TIM-related concepts:

- RQ1: What are the current challenges depicted in the literature to move towards a bioeconomy?
- RQ2: How can the emerging research landscape on bioeconomy be characterized by means of publication analysis?
- RQ3: What has been done so far within TIM research and how can associated research frames help to address the identified challenges and manage the implementation of the bioeconomy?

The remainder of this paper is structured as follows. In Section 2, definitions and drivers of the emerging bioeconomy are discussed. In order to respond to RQ1, we particularly elaborate on the challenges concerning the implementation of the bioeconomy by employing a TIM perspective. Section 3 depicts our sampling logic as well as the findings of our in-depth publication analysis on existing research concerning the bioeconomy in order to answer RQ2. Moreover, we identify TIM-related research within the context of the bioeconomy. In the following Section 4, we compare and discuss these results with the challenges identified in Section 2 to address RQ3. This gap analysis allows us to suggest various TIM research topics which might facilitate overcoming the obstacles of the bioeconomy. The study concludes with a summary of our findings and a brief discussion of limitations in Section 5.

2. Definition and challenges of the emerging bioeconomy

Before introducing current challenges accompanying the ongoing evolution process of the bioeconomy, some definitions and data on the bioeconomy are provided.

2.1. Definition and development

The term 'biobased economy' first appeared in 2000 (Eaglesham, Brown, & Hardy, 2000). Since the mid-2000s, the literature and information base on bioeconomy is gradually growing (Staffas et al., 2013). The notion itself is composed of the words 'bio' and 'economy', which implies the concept's meaning as the '*opportunity to reconcile economic growth with environmentally responsible action*' (Bioeconomy Council, 2013, p.1) or as '*the productive (economic) uses of biomass and biomass conversions*' (Staffas et al., 2013, p.2764). The existing synonyms, i.e., bio-based economy or knowledge-based bioeconomy (KBBE), are often used interchangeably (McCormick & Kautto, 2013).

The term 'bioeconomy' has emerged in different contexts, but until now, definitions mainly derive from strategic and vision-like publications provided by public and governmental institutions, e.g., by the European Commission, the OECD and national institutions (Albrecht et al., 2010; McCormick & Kautto, 2013; OECD, 2009; Rossi & Hinrichs, 2011; Vandermeulen, Prins, Nolte, & Van Huylenbroeck, 2011). The European Commission states that '*the bioeconomy encompasses all industries and economic sectors that produce, manage, or otherwise exploit biological resources (*e.g., *agriculture, food, forestry, fisheries and the industries based upon)*' (Albrecht et al., 2010, p.13). At the national level, the Federal Ministry of Food and Agriculture in Germany emphasizes the bioeconomy as '*the knowledge-based production and use of renewable resources to provide products, processes and services in all economic sectors, within the framework of an economic system which is viable for the future*' (Federal Ministry of Food and Agriculture, 2014, p.77). These two definitions indicate the often varying perspectives and scopes applied to the bioeconomy according to the institutional and disciplinary background (McCormick & Kautto, 2013; Staffas et al., 2013; Vandermeulen, Van der Steen, Stevens, & Van Huylenbroeck, 2012; Viaggi, Mantino, Mazzocchi, Moro, & Stefani, 2012). Some authors restrict bioeconomy to biotechnology (e.g., (Biotec Canada, 2008; Birch, 2009)) or focus on bioenergy (e.g., (Coleman & Stanturf, 2006)) whereas others apply a sectoral or an even more holistic view (e.g., (European Commission, 2012; Johnson & Altman, 2014; Nita, Benini, Ciupagea, Kavalov, & Pelletier, 2013; OECD, 2009; Rossi & Hinrichs, 2011)).

The status of the bioeconomy is often described as emerging or rapidly growing (Swinnen & Riera, 2013). But how can we assess this 'growth'? Analogous to the definition of the term, we still lack a standard measure in order to capture the current size of the bioeconomy as well as to monitor its evolutionary process, i.e., the transition from a fossil to a bio-based economy. The European Commission identifies 22 million employees and about 2 trillion Euro turnover within key industrial sectors of the bioeconomy in 2009 (Albrecht et al., 2010). By reading these data, one has to consider that discrepancies, e.g., about the affiliation of certain sectors such as the traditional bio-based sectors of food and feed to the bioeconomy, are present. Additionally, differences among sectors such as bioenergy and bio-based chemicals in value creation potential but also in the level of maturity and research output have to be taken into account (McCormick & Kautto, 2013). Besides using data on specific industries or products, either the amount of biomass that is used as input, e.g., in terms of revenue potentials along the biomass value chain (King, Inderwildi, & Williams, 2010), or numbers on consumer products deriving from biomass can be consulted to measure the development of the bio-based economy (Vandermeulen et al., 2011). In conclusion, a comprehensive and common definition to monitor and institutionalize the bioeconomy still needs to be developed within scientific as well as societal debates (Bioeconomy Council, 2013; European Commission, 2012; Hilgartner, 2007; McCormick & Kautto, 2013).

2.2. The role and challenges of technology and innovation management within the process of moving towards a bioeconomy

In addition to the megatrends, further forces driving and simultaneously complicating the bioeconomy evolution process have to be considered (Bioeconomy Council, 2013). As the bioeconomy has a cross-sectional character drawing upon a variety of sciences and technologies (European Commission, 2012), interdisciplinary approaches are required to address associated socioeconomic challenges (Albrecht et al., 2010; Nita et al., 2013). The bioeconomy is still in its infancy characterized by a limited knowledge base and non-availability or immaturity of required technologies for effectively utilizing renewable biomass. Additionally, a competition between different usage routes of limited biomass sources in the bioeconomy exists. Study results on the worldwide technical biomass potential range between 50 and 1500 EJ/year by 2050 due to the different underlying assumptions and evaluation methods. More realistic values for a sustainable biomass supply amount to 200–500 EJ/year (Berndes, Hoogwijk, & van den Broek, 2003; Dornburg et al., 2008; I.E.A. Bioenergy, 2009). In order to realize these biomass potentials, technologies and production systems have to be designed and managed to substitute petro-based with biomass chains (Correll, Suzuki, & Martens, 2014). To enable this transition, the promotion of innovation generating R&D and thus technological progress are decisive (Solow, 1957). Against this backdrop, TIM research helps to make the concept of bioeconomy more tangible by identifying not only its current challenges but also by providing means to foster its implementation.

In our study, three main challenges for the implementation of the bioeconomy are deduced from literature and will be explored from a TIM perspective. These challenges are associated with the transition from fossil to renewable raw materials and accompanied modifications in resource allocation and value creation as a growing number of industries competes for the same biological resources.

2.2.1. The complex knowledge base — challenge

At the beginning of new technological paradigms as represented by the bioeconomy, new knowledge and capabilities have to be created and acquired (Christensen & Rosenbloom, 1995; Dosi, Faillo, & Marengo, 2008). In consequence, the bioeconomy will become a research-intensive field to close emerging knowledge gaps and to adapt to the changing environment. This is as well implied by the notion 'knowledge-based bio-economy' (European Commission, 2012), demanding for the commitment to sustainable innovations as they are building the core of the bioeconomy (European Commission, 2012; McCormick & Kautto, 2013; Nita et al., 2013; U.S. Administration, 2012; Viaggi et al., 2012). Some publications suggest biological, particularly biotechnological, sciences to be the key for bioeconomy innovation processes (Biotec Canada, 2008; Birch, 2009; OECD, 2009). But due to its comprehensive character, the bioeconomy requires inputs from manifold scientific disciplines to grow in an efficient, sustainable manner (European Commission, 2012). As knowledge management is a central part of TIM (Nonaka, 1991; Nonaka & von Krogh, 2009), the challenges of collecting and integrating the different kinds of information and data from multiple strands need to be addressed (Teece, Pisano, & Shuen, 1997).

2.2.2. The converging technologies — challenge

The second important field often addressed in literature on bioeconomy deals with the development of new technologies across disciplines and, even more complex, across value chains (Boehlje & Bröring, 2011). Different terminologies and different approaches towards innovation, see e.g., the work on industry recipes (Spender, 1989) and on cognitive distances (Enkel & Gassmann, 2010), are exemplary barriers impeding collaborative research and technology development. Hence, capabilities to manage the cooperation among actors from different scientific backgrounds are needed. Innovations can cause spillovers implying a common science and technology base between so far distinct disciplines (OECD, 2009). For instance, the need for productivity growth in the agricultural sector and the demand for using renewable feedstock stemming from the chemical industry are interdependent and pursuing the same aim (Sheppard, Gillespie, Hirsch, & Begley, 2011). Until now, technology platforms and funding within the bioeconomy are mainly directed towards the field of bioenergy. For a sustainable development, research enabling the combination of energy and material use of biomass flows in cascading utilization or the application of different feedstock in biorefineries building a production platform for multiple industries has to be promoted (Correll et al., 2014; Kamm & Kamm, 2004; Ragauskas et al., 2006). The therewith associated process of convergence represents a major challenge addressable by TIM.

2.2.3. The commercialization and market diffusion — challenge

The market adoption and diffusion of technologies accompanying the development of the bioeconomy present the third main challenge. Innovations including the use of biological resources and materials derived from recycled waste streams or by-products from food production are often associated with novel processing technologies such as High Pressure Processing (HPP) (e.g., (Kaushik, Kaur, Rao, & Mishra, 2014)) and therefore may cause a higher risk perception among users (Ekman et al., 2013; Jensen, Halvorsen, & Shonnard, 2011; Siegrist, 2008; Verbeke, 2007). Here, one needs to distinguish between the acceptance of new products, e.g., raw materials from sides streams and products produced with novel technologies such as nanotechnology, genetic modification or irradiation (Frewer, Howard, Hedderley, & Shepherd, 1997; Schnettler et al., 2013). Not only end consumers are hesitant towards both novelties (Frewer et al., 2011). Also on the business to business (B2B) level, adoption and diffusion of technologies may be hindered by barriers like high switching costs, a lack of existing quality standards and insecurity of consumer responses (Henchion et al., 2013). This implies successful product and process development within a bio-based economy to be more complicated as societal concerns have to be taken into account (Paula & Birrer, 2006). Overcoming the currently low acceptance rate of both novel raw materials in food production as well as novel technologies thus presents an urgent task for TIM research.

3. Publication analysis

In the following, the data basis, sampling logic and the resulting findings of the publication study are presented in order to display existing research on bioeconomy.

3.1. Data and method

The publication analysis is conducted in two literature databases to ensure a comprehensive coverage of well-established as well as emerging academic journals. The databases SciVerse Scopus provided by Elsevier B.V. and Web of Science™ Core Collection (WoS) made available by Thomson Reuters include the contents of 20,000 and over 12,000 journals, respectively, and thus a broad range of research topic areas (Elsevier B.V., 2014; Thomson Reuters, 2014).

The search string combining the terms 'bio-based econom * OR biobased economy * OR bio-econom * OR bioeconom * OR bio-based OR biobased' within title, abstract and keywords of journal articles and reviews aims at receiving the status quo of the research landscape on bioeconomy. As the data on publications of the year 2014 has not been fully available at the point of analysis, our sample covers the time frame from 1980 to 2013. The overall development of publications and activities of different disciplines is presented, whereby socioeconomic and environmental science articles within TIM research are analyzed in detail. The analysis tries to identify TIM-related concepts which the respective authors applied to the context of bioeconomy. We then discuss to what extent the existing work may help to better understand the three main identified challenges associated with the implementation of the bioeconomy.

3.2. Findings of the publication analysis

The numbers of resulting publications account for 1720 in the Scopus and 3439 in the WoS database for the period from 1980 to 2013, whereby the time development reflects a rising interest in bioeconomy with a surge after the year 2002. This increase as well as the overall amount of publications are considerably higher in WoS which might result from different search algorithms, particularly from searching in the 'keywords plus' extracted by Thomson Reuters (from the respective cited references) next to the author keywords. The amount of documents that has been published before 1980, i.e., 15 in Scopus and 6 in WoS, and between 1980 and 2000, i.e., 190 in Scopus and 273 in WoS, is rather negligible. A similar trend has also been monitored by Vandermeulen et al. (2011) in a bibliometric analysis searching for 'bio(based)economy'. The first publication on the bio-based economy emerged in 2000, i.e., Eaglesham et al. (2000), while most governmental strategies have been published after 2004. When considering the time lag between first publications and their citations, our findings correspond to results from Staffas et al. (2013) who show that the number of citations for publications including bioeconomy or bio-based economy experienced a boost both after 2005 and 2010. Although citations reflect the impact on the research community, a citation analysis was not conducted here as most publications are relatively new, so that the sample of citation counts would be too low to derive meaningful conclusions.

To obtain publications relevant to answer our research questions, the resulting data set is progressively refined (see Fig. 1).

By comparing the activities of different subject areas, the share of articles in terms of socioeconomic and environmental sciences accounts for 37% (Scopus) and 17% (WoS) of all publications, respectively.[1] Activities within natural sciences, i.e., life and physical sciences, prevail. Vandermeulen et al. (2011) also recognize that scientific articles on bio-based topics as well as specifically on bioeconomy are seldom stemming from an economic perspective. Within the socioeconomic and environmental science area, particularly the low publication activities (2–3%) within the categories business and management already indicate the small amount of articles and research activities in the domain of TIM research.

Applying additional search terms specifying the TIM research landscape and combining the results from both databases while eliminating duplicates, results in a sample of 209 articles. Two of the authors independently scan these publications regarding their fit to the bioeconomy and against the backdrop of the TIM research frames described in Section 2.2. Thereby, articles dealing with bioeconomic modeling approaches[2] or publications that are not referring to our understanding of bioeconomy are excluded from further analysis. 74 publications are using the bioeconomy as an overall setting and are mainly dealing with policy aspects, life cycle assessment (LCA) or subordinated (bio)technological issues mostly concerning bioenergy or bio-based chemicals and bear no relation to TIM research (see Table 1). Thus, only 12 publications serve for the discussion on TIM research frames within the bioeconomy.

These 12 publications (see Table 2) dealing with questions of TIM are combining different scientific research designs like interviews, qualitative case studies, surveys or analyses of secondary data. Four articles are based on conceptual analyses (Boehlje & Bröring, 2011; Levidow, Birch, & Papaioannou, 2013; Paula & Birrer, 2006; Wield, 2013) and two others on scientometric analyses (Cooke, 2006, 2009). It is noticeable that bioeconomy rather serves as a framework for discussion, so that clear definitions of bioeconomy are often missing. The main findings concern the importance of promoting (industrial) biotechnology and its acceptance, development of required resources, open innovation approaches and the high impact of governmental policies. However, these key learnings are often limited to specific conditions and spatial capabilities as nearly all articles argue from a particular national, regional or industry sector perspective with regard to innovation (Ahn, Hajela, & Akbar, 2012; Szogs & Wilson, 2008). Pursuing and gaining competitiveness in the bioeconomy is often emphasized (e.g., (Dunham, Ahn, & York, 2012; Theinsathid, Chandrachai, & Keeratipibul, 2009)) and therefore corresponding to the content of published national strategies illustrating bioeconomy or biotechnology as competitive factor of a nation or industry (e.g., (European Commission, 2012; Federal Ministry of Education and Research, 2010)).

4. Discussion: Matching emerging challenges of the bioeconomy with research frames of TIM

To face the three identified challenges arising within the emerging bioeconomy, a framework for discussion is introduced. This draws on a process perspective reaching from basic research to market introduction and thus encompasses R&D as well as technology management (Specht, Beckmann, & Amelingmeyer, 2002). As depicted in Fig. 2, the process provides a basis to further refine the three challenges which appear to be suitably addressed by specific TIM research frames. At first, the 12 TIM-related studies identified in the publication analysis are scanned to determine if and to what extent they deal with topics facing the identified challenges. As the studies only introduce first insights, further literature is consulted. Due to the specific environment, numerous open questions remain which can be tackled by adapting established TIM concepts to the specific context of the emerging bioeconomy.

[1] This group includes the following subject areas in Scopus: Business/Management/Accounting, Decision sciences, Economics/Econometrics/Finance, Environmental sciences, Social sciences; and in the WoS categories: Business, Environmental sciences, Environmental studies, Economics, Management, Operations management research, Social issues, Sociology. It has to be considered that one article (or rather the underlying journal) can be classified to several subject areas at the same time. Therefore, the amount of assignments and not the number of articles builds the basis for calculating the shares.

[2] Bioeconomic modeling approaches combine economic and biological or biophysical models often applied in fishery and marine or in agricultural (economics) research, e.g., for questions concerning land use.

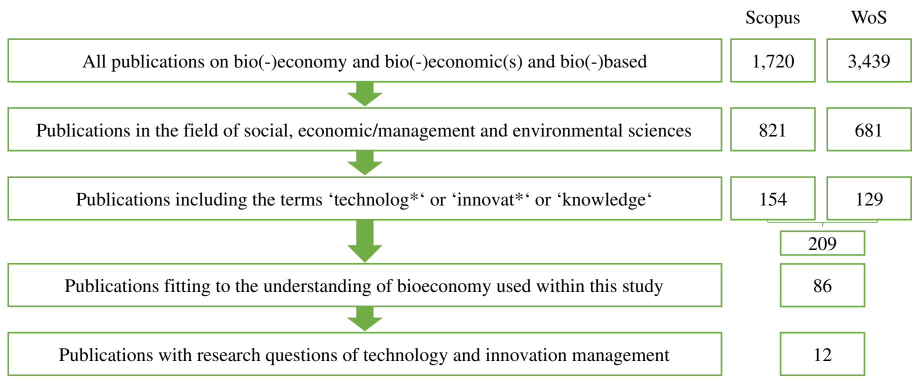


Fig. 1. Sampling logic for the publication analysis and the resulting numbers of publications in the databases Scopus and Web of Science during the period between 1980 and 2013.

4.1. Research frames concerning the complex knowledge base — challenge

The dynamic and complex environment of the bioeconomy requires new value-adding processes that are premised on new knowledge which is challenging for academia as well as industry. The ability to integrate as well as to reconfigure external competencies and resources are decisive to create new knowledge and pursue innovations for adapting to this changing environment (Afuah, 2003; Cohen & Levinthal, 1990; Teece et al., 1997; Zahra, 2002).

4.1.1. Knowledge management within the changing environment

The evolution of the bioeconomy is considered to be knowledge- and technology-driven (Cichocka et al., 2011; European Commission, 2012), whereby biotechnology is often seen as first priority (e.g., (Ahn et al., 2012)) but the importance of life sciences, agronomy, ecology, engineering and management sciences is as well emphasized (European Commission, 2012). Hence, multiple forms and flows of knowledge from different disciplines and actors lead to complex structures and new fields of knowledge. In this early phase which is characterized by uncertainty, the area of TIM research provides methods to anticipate and monitor scientific developments in terms of publications and patents. Furthermore, (co-) citation, co-word and co-authorship analysis can be applied to determine the extent of knowledge exchange and collaboration between different technology bases to prepare for future competitive settings (Curran, Bröring, & Leker, 2010; Debackere, Verbeek, Luwel, & Zimmermann, 2002; Ernst, 1997; Grupp, 1998; Meyer, 2000; Spender & Grant, 1996). Three studies of our meta-analysis apply the mentioned tools to the field of bioeconomy. While Birch (2009) uses the number of publications to determine the status of geographically distributed knowledge assets in biotechnology clusters, Cooke (2006, 2009) conducts scientometric analyses of bioscientific co-publications (connecting biotechnology and healthcare) to identify spatial knowledge flows and spillovers. In addition to determining evolving key knowledge areas and key actors to capture future opportunities of value creation, the integration of various expertise and research across different scientific fields is e.g., required to enable developing economic feasible technologies in order to process biomass, particularly lignocellulosic feedstock, to a wide range of products (Boehlje & Bröring, 2011; Dunham et al., 2012; Kajikawa & Takeda, 2008). Thus, iterative and interactive learning has to be managed beyond firm boundaries for balanced innovation processes (Caraça, Lundvall, & Mendonça, 2009; Debackere et al., 2002). For instance, Szogs and Wilson (2008) suggest enhancing collaborative efforts to create new scientific knowledge via collective learning when examining the development of biomass technologies. Levidow et al. (2013) state that within an agro-ecology vision of the bioeconomy, the creation of new knowledge occurs via the cooperation between farmers and researchers but also collectively with all stakeholders of the agri-food chain (in technology platforms). Wield (2013) agrees by stating that knowledge creation requires input from complementary sources. Here, the literature around the knowledge-based view (Grant, 1996) in combination with the relational view (Dyer & Singh, 1998) appears to be useful as it understands the network of firms to be the locus of innovation and consequently a source of competitive advantage. This concept seems to be valuable for the bioeconomy as innovation system or network approaches for theme-oriented instead of sector-based research are suggested to be expedient in this cross-disciplinary environment (European Commission, 2012; Vandermeulen et al., 2012).

4.1.2. Open innovation to fill competency gaps

Due to the changing resource base, radical innovations are needed to enable the associated switch to new production chains. As firms have to face the wide emerging gap between existing and required capabilities (Du Plessis, 2007), one option for firms in order to close the gap and share the risk suggested from TIM research is 'open innovation' which is characterized by engaging in exploratory research and utilizing complementary knowledge from external sources while leveraging

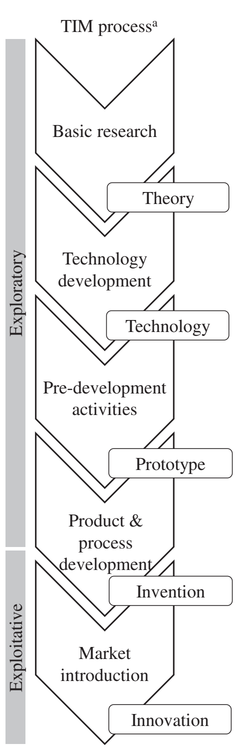
Table 1
Assigning the 209 publications deriving from the publication analysis to different groups by means of their thematic emphasis. Multiple assignment to different topics is possible.

	Publications fitting to the understanding of bioeconomy used within this study				Publications addressing the wider context of agricultural systems and modeling	
	Publications dealing with research questions of TIM		Publications not dealing with research questions of TIM			
Number of publications		12		74		123
Thereof (Multiple assignment to topics is possible.)	Addressing the complex knowledge base – challenge	9	Focusing on general or policy aspects	16	Using bioeconomic modeling	87
	Addressing the converging technologies – challenge	6	Focusing on bioenergy, bio-based chemicals or biorefinery	51		
	Addressing the commercialization and market diffusion – challenge	5	Focusing on LCA/sustainability assessment	13		
			Focusing on other aspects (e.g. industrial biotechnology)	13		

Table 2
List of publications addressing research questions of TIM.

	Authors	Year	Publication title	Research design
1	Ahn, M.J.; Hajela, A. and Akbar, M.	2012	High technology in emerging markets: Building biotechnology clusters, capabilities and competitiveness in India	Case studies including interviews Survey
2	Atwell, R.C.; Schulte, L.A. and Westphal, L.M.	2009	Linking Resilience Theory and Diffusion of Innovations Theory to Understand the Potential for Perennials in the U.S. Corn Belt	Interviews
3	Birch, K.	2009	The knowledge-space dynamic in the UK bioeconomy	Interviews Survey Secondary data
4	Boehlje, M. and Bröring, S.	2011	The increasing multifunctionality of agricultural raw materials: Three dilemmas for innovation and adoption	Conceptual analysis
5	Cooke, P.	2009	The economic geography of knowledge flow hierarchies among internationally networked medical bioclusters: A scientometric analysis	Scientometric analysis
6	Cooke, P.	2006	Global bioregional networks: A new economic geography of bioscientific knowledge	Case study Market analysis Survey
7	Dunham, L.; Ahn, M.J. and York, A.S.	2012	Building a bioeconomy in the heartland: Bridging the gap between resources and perceptions	Case study including interviews Survey Secondary data
8	Levidow, L.; Birch, K. and Papaioannou, T.	2013	Divergent Paradigms of European Agro-Food Innovation: The Knowledge-Based Bio-Economy (KBBE) as an R&D Agenda	Conceptual analysis
9	Paula, L. and Birrer, F.	2006	Including public perspectives in industrial biotechnology and the biobased economy	Conceptual analysis
10	Szogs, A. and Wilson, L.	2008	A system of innovation? Biomass digestion technology in Tanzania	Case studies including interviews
11	Theinsathid, P.; Chandrachai, A. and Keeratipibul, S.	2009	Managing bioplastics business innovation in start-up phase	Interviews Secondary data
12	Wield, D.	2013	Bioeconomy and the global economy: Industrial policies and bio-innovation	Conceptual analysis

the own (Chesbrough, 2003; Cohen & Levinthal, 1990; Enkel & Gassmann, 2010). A contingency approach is needed to decide about the suitability of an open innovation management which is e.g., recommended in case of high knowledge and technology intensity (Gassmann, 2006). Hence, the authors of our meta-analysis dealing with TIM in the bioeconomy also promote this concept. For instance, Wield (2013) observes that pharmaceutical innovation processes are increasingly characterized by openness (to involve more actors from other nations) and biotechnology. Theinsathid et al. (2009) suggest participating and benefiting from open networks to absorb knowledge especially from customers in order to contribute to the multidisciplinary R&D in Thailand's bio-plastics sector. Ahn et al. (2012) as well as Dunham et al. (2012), arguing from a resource-based view perspective (e.g., based on Wernerfelt (1984)), promote the identification and



Emerging challenges of the bioeconomy deduced from literature	TIM-related research frames	Existant research[b]		
		(Inter-) National level	Industry level	Firm level
Complex knowledge base	▪ Knowledge management within the changing environment ▪ Open innovation to fill competency gaps	1, 3, 5, 6, 7	1, 3, (4), 5, 6, 7, (8), 11, (12)	
Converging technologies	▪ Technology transfer for sustainable innovation ▪ Technology convergence and converging value chains	1, 10	1, (4), 6, (8), (12)	10
Commercialization and market diffusion	▪ Technology adoption and diffusion (B2B) ▪ Technology acceptance (B2C)	(9), 10, (11)	2, (4), (9), (11)	10

[a] Technology and innovation management process according to Specht, Beckmann, & Amelingmeyer (2002).
[b] Publications addressing the listed topics are 1. Ahn, Hajela, & Akbar (2012), 2. Atwell, Schulte, & Westphal (2009), 3. Birch (2009), 4. Boehlje & Bröring (2011), 5. Cooke (2009), 6. Cooke (2006), 7. Dunham, Ahn, & York (2012), 8. Levidow, Birch, & Papaioannou (2013), 9. Paula & Birrer (2006), 10. Szogs & Wilson (2008) and 11. Theinsathid, Chandrachai, & Keeratipibul (2009) and 12. Wield (2013). Conceptual work is characterized by parenthesized numbers.

Fig. 2. Comparison of identified challenges with research frames in the TIM process. Existant research efforts are classified to topics according to their research questions and unit of analysis.

accumulation of required resources to build capabilities in order to form biotechnology industry clusters including complementary partners as well as competitors for a competitive bioeconomy ecosystem. By studying the geographically-specific development of the bioeconomy in the UK, Birch (2009) finds that the formation of capabilities for biotechnology innovation differs due to different patterns of knowledge exchange and varying spatial relationships. Cooke (2006, 2009) concludes from his scientometric analysis that the dynamic capabilities required to manage the bioeconomy are located in knowledge networks which resulted from open research approaches. All of these authors emphasize frequent interactions (not necessarily geographic proximity) between knowledge partners, high absorptive capacities and thus effective spillovers of particularly tacit competencies (Ahn et al., 2012; Birch, 2009; Cooke, 2009).

4.2. Research frames concerning the converging technologies — challenge

The second challenge emerging within the bioeconomy focuses on managing the technology development occurring in cooperation between actors originating from distinct value chains and interrelated impacts.

4.2.1. Technology transfer for sustainable innovation

The technological change accompanying the bioeconomy is a lengthy process. As most technologies required for implementing the bioeconomy are so far not economically viable, the concept of technology transfer might contribute to promote their evolution. Thereby, improving the transfer of knowledge and technologies from research projects to application appears to enhance the effectiveness of technology evolution (Bozeman, 2000; Lee, 1996). In addition, technology transfer between partners along the value chain as well as across sectors is required to induce sustainable innovations (Tatikonda & Stock, 2003). In case of lacking competencies, firms have to leave extant paths to find ways of integrating new technological knowledge and to retain competitiveness (Brunswicker & Hutschek, 2010; Dosi, 1982; Enkel & Gassmann, 2010; Nesta & Dibiaggio, 2003; Sydow, Schreyögg, & Koch, 2009). Utilizing and aligning technologies established in other industries to the own context can promote the innovative performance if they are valuable for different applications (Brunswicker & Hutschek, 2010; Rosenberg, 1963) which is e.g., assumed for key enabling technologies like biotechnology (Wield, 2013) or illustrated by the use of ultrasonic technologies in the food sector for several applications such as emulsification or (in-) activation of enzymes (Patist & Bates, 2008). For the bioeconomy, partnerships between academia and industry are suggested to facilitate technology transfer (European Commission, 2012), particularly to effectively distribute resources in biotechnology research (Ahn et al., 2012; Lane & Lubatkin, 1998). Forming value networks, especially with new actors, is suggested to enable the development of new radical technologies and processes (Christensen & Rosenbloom, 1995). These holistic approaches to knowledge and technology management might be favorable for accelerating growth within the bioeconomy (OECD, 2009).

4.2.2. Technology convergence and converging value chains

As mentioned before, in consequence of a common resource base, the competition between different sectors will increase and the technology base of different value chains will merge. These developments and the resulting decreasing distance might be described by technology convergence processes (Bröring, 2010; Rosenberg, 1963). This process can be technology/input-driven or market/output-driven and is likely to affect established industry value chain structures (Bröring, 2010; Lei, 2000; Pennings & Puranam, 2001), whereby a full convergence process includes technology as well as market convergence (Curran & Leker, 2011). Two publications within our sample deal with convergence in the context of bioeconomy. Boehlje and Bröring (2011) see an input-/technology-driven disruption of processes and blurring of boundaries as similar knowledge and technologies become important for various sectors utilizing the same agricultural resource base. Levidow et al. (2013) agree when discussing the 'life sciences vision' where (the use of generic knowledge and) converging technologies lead to the horizontal integration of agriculture with other industries. Thereby, new value-added chains connecting the production of biomass, chemicals and energy have to be designed by an integrative application of technologies (Kircher, 2012; OECD, 2009). The resulting new competitive settings demand for acquiring new capabilities and resource access via collaborations and open innovation approaches (Boehlje & Bröring, 2011).

4.3. Research frames regarding the commercialization and market diffusion — challenge

Commercialization being defined as '*the conversion of a scientific idea from research into a product*' (Rogers, 2003, p. 152) presents the final step of the innovation value chain. Moving a R&D project from exploration to exploitation itself is a challenging act, which becomes even more complex in the context of emerging technologies respectively markets (Tripsas, 2000) as rate and pace of diffusion are different in case of radical technologies (Day, 2000). Therefore, the research frames of technology adoption and diffusion (B2B) and technology acceptance (B2C) are elaborated in the following.

4.3.1. Technology adoption and diffusion (B2B)

In order to move to new paradigms, new technology platforms need to be established. The large research body on the antecedents of technology adoption and diffusion identified one major challenge, i.e., to find an early adopter who is willing to switch from conventional to new processes or products (Feder & Umali, 1993; Rogers, 2003). The rate of adoption depends on different variables like e.g., the innovation's profitability (Rogers, 2003), whereby the diffusion process (Geroski, 2000) is e.g., contingent on establishing new industry standards (David & Greenstein, 1990). The cooperation between different actors along the value chain contributes to the adoption and routines of other technology domains. This enables organizations to think outside the own dominant logics to challenge the 'not-invented-here syndrome' as a barrier to adopt innovations (Brunswicker & Hutschek, 2010; Cohen & Levinthal, 1990; Herzog & Leker, 2010; Katz & Allen, 1982). This issue is also discussed within the sample of our meta-analysis. Szogs and Wilson (2008) identify a slow adoption rate and only isolated initiatives when local actors try to adopt technologies developed internationally. A slow technology adoption has also been identified by Atwell et al. (2009), whereby in-depth interviews with corn farmers in Iowa reveal the adoption of new farming practices to depend on e.g., the compatibility with the existing technological base, collaborative learning and institutional reinforcement (i.e., straightforward regulation and incentives). Moreover, for the technological change accompanying the transition from a fossil to a bio-based economy, a critical mass of bio-based resources has to be generated to implement the bioeconomy. In order to achieve that critical mass, more research within the context of the bioeconomy is needed to better understand what drives early adopters and lead users (Von Hippel, 1986) at business-to-business level.

4.3.2. Technology acceptance (B2C)

Consumer acceptance on B2C level is mainly based on several theoretical frames rooted in consumer sciences like the theory of planned behavior (Ajzen, 1991). Most frequently, existing research refers to Davis' technology acceptance model (TAM) which draws on social psychology research (Davis, 1986). Acceptance is found to increase with knowledge and perceived usefulness (Davis, 1989; Davis, Bagozzi, & Warshaw, 1989). Hence, lack of knowledge regarding innovative and emerging bio-based technologies as well as new resources can serve as a major impediment to their acceptance across the entire value chain and therefore inhibiting technology advances

(Viaggi et al., 2012). Existing studies on the risks and benefits of novel (food) technologies reflect the, yet, limited acceptance of new materials and technologies, especially in Europe (Cox, Evans, & Lease, 2007; Frewer et al., 2011; Siegrist, 2008). Regarding the utilization of side streams to close value cycles as one basic idea of the bioeconomy, publications within the meta-analysis find that there is limited acceptance for most products stemming from or generated with biotechnological processes (Paula & Birrer, 2006). However, at the same time more environmental sound solutions are demanded from society. It is evident that the limited acceptance by consumers in turn affects the technology acceptance and adoption on industry level (Boehlje & Bröring, 2011). To build awareness of consumers regarding renewable feedstock products or even to create a demand-pull, Theinsathid et al. (2009) suggest integrating consumers and particularly lead users into the innovation process. In a similar vein, Paula and Birrer (2006) demand firms to engage in extensive social dialog to enhance public acceptance. Moreover, by looking at the product level, it seems that the implementation is largely a communication issue as credence attributes such as bio-renewable resources not verifiable by a consumer require extra information through specific certifications or quality labels (Verbeke, 2007). The same holds true for the usage of alternative raw materials such as insect proteins which do currently not only face regulatory (see EU Novel Food Legislation EG No. 258/1997) but also challenges rooted in consumer acceptance (Rumpold & Schlüter, 2013).

Notwithstanding the weak focus on the emerging bioeconomy as a research setting and the context-dependency of extant results, various TIM research frames on a rather high abstraction level appear to be applicable to the challenges of the emerging bioeconomy. The presented theory frames may help to understand and possibly mitigate the current challenges but more bioeconomy-specific studies on each aspect are needed. Other important research frames concerning the bioeconomy and partially addressed in the 12 publications but not discussed in detail here are e.g., dealing with the development of governmental frameworks and associated funding as well as regulation-induced innovations (Ahn et al., 2012; Albrecht et al., 2010; Szogs & Wilson, 2008; Wield, 2013), opportunities for developing countries (Wield, 2013) and market development within the bioeconomy (Carus, Carrez, Kaeb, Ravenstijn, & Venus, 2011; Taheripour & Tyner, 2008).

5. Conclusions and implications

The results of our analysis indicate that the evolution of the bioeconomy is currently on a strategic level. Although the literature base is increasing, the number of scientific studies is still low and not dealing specifically with the bioeconomy on firm or consumer level. The publications consciously dealing with bioeconomy as economic concept and approaching to transfer results that are until now rather limited to natural sciences into a broader picture are rare. As there is no common understanding of the concept on bioeconomy and the roles of actors and technologies are uncertain, we confirm the necessity to promote as well as to institutionalize the bioeconomy as already postulated by Viaggi et al. (2012) or Staffas et al. (2013).

A variety of challenges accompanies the bioeconomy evolution resulting from a changing resource base and the associated modified value creation. The three main issues are relating to a new, complex knowledge base, cross-chain technology development as well as commercialization. Research frames from TIM are suggested to address these challenges. The studies deriving from the meta-analysis already partially provide insights concerning TIM within the bioeconomy. Thereby, open innovation approaches and collaboration across value chains to develop the required knowledge and technologies are promoted to enable comprehensive, interdisciplinary research on organizing future biomass flows across sector boundaries.

The limitations of our meta-analysis are mainly based on the choice of keywords as well as on scanning the resulting sample for relevant studies. Although careful research has preceded the analysis, a certain degree of subjectivity remains. The selected keywords can prevent detecting important research in scientific literature as articles often deal with very specific topics and do not explicitly refer to the keywords used, whereas we target bioeconomy on a more aggregated level. In addition, the transparency of assigning articles or rather journals to subject areas or WoS categories is disputable as multiple counts are possible.

The existing body of research in the area of TIM provides a good basis but it seems rather abstract and previous results are often difficult to transfer to the bioeconomy environment. In order to close this gap, we call for more bioeconomy-specific studies to face the three challenges discussed. To contribute to the development and tangibility of bioeconomy, focus should be set on how to best manage collaborations between different disciplines to obtain radical innovations necessary for growth in the emerging bioeconomy and on how to establish standardized measures allowing to track the implementation of the bioeconomy.

Acknowledgments

We would like to thank the participants of the 9th International European Forum (Igls-Forum) on System Dynamics and Innovation in Food Networks and in particular Nina Preschitschek for valuable comments on an earlier version of this study.

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