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The potential contribution of transition theory to the analysis of bioclusters and their role in the transition to a bioeconomy

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Suggested Citation: Hermans, Frans (2018) : The potential contribution of transition theory to the analysis of bioclusters and their role in the transition to a bioeconomy, Biofuels, Bioproducts and Biorefining, ISSN 1932-1031, Wiley, Hoboken, NJ, Vol. 12, Iss. 2, pp. 265-276, https://doi.org/10.1002/bbb.1861 , https://onlinelibrary.wiley.com/doi/abs/10.1002/bbb.1861

This Version is available at:
https://hdl.handle.net/10419/175844

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Review

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The potential contribution of transition theory to the analysis of bioclusters and their role in the transition to a bioeconomy

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Received August 30, 2017; revised December 4, 2017; accepted December 15, 2017
View online at February 19, 2018 Wiley Online Library (wileyonlinelibrary.com);
DOI: 10.1002/bbb.1861; *Biofuels, Bioprod. Bioref.* 12:265–276 (2018)

Abstract: Biocluster initiatives have become an important tool for governments to establish, promote, and strengthen economic collaboration, learning, innovation, and employment within particular regions. However, in addition to issues like competitiveness and employment, bioclusters operate with the additional goal of fostering the transition to a sustainable bioeconomy. The profound changes that are required for a successful shift from a fossil-based economy to a bioeconomy are called transitions and the relatively new scientific field of transition theory has emerged to study them. The aim of this paper is to show the contribution that transition theory can make to the study of bioclusters. In this paper I will review frameworks from the study of sustainability transitions (multi-level perspective and technical innovation systems) and frameworks from theories of evolutionary economic geography and cluster studies (regional and sectoral innovation systems). The review shows how the choice of a particular framework will shape the analysis of the biocluster through the particular focus and delineation associated with each framework. The review shows the advantages and disadvantages these frameworks have for incorporating the various issues related to the shift towards a bioeconomy that are currently neglected in the literature on bioclusters. © 2018 The Authors. *Biofuels, Bioproducts, and Biorefining* published by Society of Chemical Industry and John Wiley & Sons, Ltd.

Keywords: bioclusters; innovation; innovation systems; multi-level perspective (MLP); sustainability transitions

Introduction

The growing global population, which will become increasingly affluent, combined with the projected effects of climate change, requires a major shift in the way food, energy, and raw materials are produced, consumed, processed, and disposed of. The concept of the bioeconomy has received increasing attention as a potential solution for these problems. The bioeconomy encompasses the production of renewable biological resources (biomass like wood, plants, and algae) and the conversion of these resources and their waste streams into value-added products, such as food, feed, bioplastics, pharmaceuticals, and bioenergy.[1] The ultimate goal of the bioeconomy is to replace our current fossil-based sources of carbon with renewable sources of carbon that are based on photosynthesis.

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In addition to the shift away from a fossil-based economy toward renewable energy, the bioeconomy promises to contribute to the creation of new economic opportunities – for instance, through new business formation and entrepreneurship, increased resource efficiency, energy independence, and employment creation in knowledge-based sectors related to biotechnology and genomics, plant breeding, and plant-based processing. The concept of the bioeconomy is therefore not only closely associated with goals of environmental sustainability and energy independence but also with innovation and the valorization of scientific knowledge.[2] These promises have made the concept of the bioeconomy very popular with policy makers in the European Union, as well as in other countries like the United States, Brazil, South Africa, and China.[3,4]

However, the shift away from fossil-based sources of carbon is likely to require more than just the development of new technological alternatives (hardware). Nowadays it is increasingly acknowledged that innovations should be viewed as successful combinations of hardware with software (new knowledge and new modes of thinking) and orgware (reordering institutions and organizations).[5] In an increasingly interconnected society, the success of an innovation depends on changes up and down the value chain and on numerous social processes in which multiple actors from society, government, science, agriculture, and industry interact. This means that a single actor is unlikely to possess all the knowledge and resources to push through a particular innovation and that collaboration and learning processes between multiple stakeholders is necessary.[6]

Ever since the seminal work of Michael Porter, cluster initiatives have become an important tool for governments to establish, promote, and strengthen economic collaboration, learning, innovations, and employment within a certain region. Porter defined a cluster as 'a geographically proximate group of interconnected companies and associated organizations (for example, universities, standards agencies, and trade associations) in a particular field, linked by commonalities and complementarities.'[7] This paper focuses on bioclusters: clusters that specialize in the various fields of the bioeconomy and that are expected to play a key role in its development.[8,9] Bioclusters are therefore a special kind of cluster that operate with the explicit goal of sustainable development by fostering the transition to a bioeconomy.[10–12]

In this paper I argue that the added goal of sustainable development makes it important to study the functioning of bioclusters beyond the traditional focus on competitiveness and employment. A successful shift from a fossil-based economy to a bioeconomy requires a radical reorientation of production and consumption processes. These profound societal changes are called transitions, and the relatively new scientific field of sustainability transitions or transition theory has emerged to study them.[13,14]

Bioclusters therefore operate on the intersection of two scientific fields related to the bioeconomy: sustainability transitions and a subfield of economic geography called evolutionary economic geography. The aim of this paper is to show the contribution that transition theory can make to the study of bioclusters. Even though the main focus of the paper relates to the contribution of transition theory, I will include some of the more recent developments within evolutionary economic geography that are relevant for the study of bioclusters as well. This paper thus wants to make a theoretical contribution by analyzing the strengths and weaknesses these two different approaches hold for the study of bioclusters. Doing this will also help to shed a new light on the concept of a biocluster and its functioning.

I start with a review of some of the developments in cluster theory beginning with the work of Michael Porter and ending with the field of evolutionary economic geography. Next, I review transition theory and one of the main frameworks to which it applies: the multi-level perspective. In the final section, I discuss the innovation system framework, which has been applied, albeit in somewhat different forms, by both transition theory (in the form of *technical* innovation system) and evolutionary economic geography (in the form of *regional* innovation systems). In the final discussion section I will discuss how the study of bioclusters can help in both the further development of cluster theory and transition theory.

Cluster theory

The study of the distribution of economic activities over different geographical locations has its roots in the work of Alfred Marshall who studied the geographical concentration patterns of British firms in late nineteenth-century Britain. He showed how firms concentrated the manufacture of certain products in geographically clustered districts.[15] Later contributions have been made by (among others) Paul Krugman and New Economic Geography who studied the economics of agglomeration processes.[16,17] In this regard, it is important to make a distinction between the study of these more-or-less natural agglomeration processes and the active intervention of governments trying to establish new clusters.

Clusters as a specific goal of government interventions were popularized in particular by the work of Michael

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Porter.[7] Based on the literature on the competitiveness of different nations, he came up with a framework that has become known as Porter's diamond. The idea behind the diamond is that competitiveness, productivity, and economic growth depend on the business environment in a specific location. This local context can be split up into four key elements that make up the four sides of the diamond: 1) factor conditions such as technologies, and capital, 2) demand conditions from (technically sophisticated) customers, 3) links to related and supporting industries, and 4) firm strategies, structure, and rivalry. The more developed and intense the interactions between these four sets of factors are, the greater the productivity of the concerned firms will be. In his work *The Competitive Advantage of Nations,* Porter made the observation that a country's most competitive companies are often geographically concentrated in just a number of places: clusters. From that observation, it was a small step to promote actively the creation of new clusters to encourage general competitiveness and growth: geographical clustering of firms increases the interaction of the four elements of the diamond and is therefore thought to be beneficial for regional development.

Although the work of Porter has been very popular, especially with policy makers and practitioners, the scientific community has been far more critical.[18,19] One of the most often repeated criticisms of Porter's cluster theory is the lack of a clear definition regarding the boundaries of a cluster. Clustering and agglomeration processes are partly natural processes that occur when a number of sector-related industries are founded within each other's vicinity. Depending on the type of economic activities, a cluster can be located within a city (e.g. the financial cluster known as Wall Street) but it can also cross municipal, regional, and sometimes even national geographical boundaries. This makes it difficult to choose a natural geographical or administrative boundary for a cluster and it often leads to subjective and arbitrary cluster boundaries in many studies.[19]

Bioclusters as Porter's clusters

The contested definition of the concept of the bioeconomy itself exacerbates the problem of defining what a biocluster is. At the moment there are different definitions of the concept of the bioeconomy, often with a slightly different label: bioeconomy, bio-based economy, knowledge-based bioeconomy and a discussion whether the inclusion of the concept of the circular economy is an intrinsic part of a sustainable bioeconomy.[1,2,20,21] These different definitions thus influence which economic sectors are to be included in the definition of a biocluster and where to delineate its boundaries.

Despite its analytical weaknesses, current policy literature on bioclusters treats bioclusters like any other type of cluster. As a result the literature is dominated by studies that focus on competitiveness, employment, and innovation. The view on bioclusters mirrors the more general view on the bioeconomy in this regard. This literature focuses on the stated goals of the bioeconomy as knowledge creation, employment, and new business opportunities, and it somewhat neglects issues of sustainability and environmental innovations, which are also an indispensable part of the transition to a bioeconomy.[22,23]

The fact that many bioclusters typically operate in high-tech industry only enhances this narrow view. Costs are mostly associated with research and development and less with the production costs of the biomass that are used as inputs. However, claims about the regional development and employment potential of high-tech bioclusters are questioned by Birch,[24] who argues that there is limited evidence that the life-science sector represents a major employer or a major contributor to economic growth in the regions where the British life sciences are clustered. In order to bring the issue of sustainable development more to the forefront, a new perspective on bioclusters is necessary. This perspective can be provided by the inclusion of transition theory in the study of bioclusters.

Sustainability transitions

Transition theory studies long-term processes of transformation that require a combination of technical, organizational, economic, institutional, social-cultural, and political changes.[25] Transition theory holds an evolutionary perspective of innovation: various novelties and their associated innovation coalitions compete in a dynamic selection environment in which the best fitting ones survive. However, the concept of co-evolution suggests that such fitting does not only involve adaptation to prevailing contextual conditions but also involves attempts to influence, redesign, or destroy them.[26–28] Governance approaches derived from transition theory, like strategic niche management[29] (SNM) and transition management[30] (TM), have an explicit goal of contributing to sustainable development. Through the analysis of historical case studies (SNM), or practical action research (TM), the idea is to draw lessons that will help to develop and implement more sustainable alternative technologies and practices.

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The multi-level perspective

The multi-level perspective, or MLP for short, has been developed, especially within the context of strategic niche management. The MLP is used to explain how local knowledge and innovations spread from the micro levels of small groups of innovators to the higher macro levels in society. The MLP makes a distinction between three more-or-less hierarchical levels of niches, regimes, and socio-technical landscapes that form the micro, meso, and macro levels of bottom-up socio-technological development processes.[31]

Technological niches form the micro level where radical novelties emerge. These novelties are initially unstable configurations with a low performance. The actors in these niches are prepared to accept this low performance and higher costs and are willing to work to improve the new technology. Niche innovations are therefore often carried out and developed by small networks of dedicated outsiders.[32] Within a niche three internal processes have been identified that are important for its development over time: 1) the articulation and subsequent convergence of visions, 2) learning and experimentation, and 3) the building of relational networks.[33] The convergence of actors' visions refers to the degree to which their strategies, expectations, beliefs and practices go in the same direction. Learning and experimentation is done within these niches, which rely on the contribution of a network of multidisciplinary stakeholders to be involved. Networking is necessary to make sure the most relevant actors become involved in the niche. Successful experiments can be used to interest new actors and make the niche's network grow and develop over time.[34,35]

The socio-technical regime is an extended version of the technological regime of Nelson and Winter.[36] Rip and Kemp[37] define a socio-technical regime as 'the grammar, or rule-set comprised in the coherent complex of scientific knowledge, engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of defining problems, all of them embedded in institutions and infrastructures.' As such, a regime has a cognitive part, namely the collective knowledge shared among members of the regime: their rules, facts, and information.[38,39] A socio-technical regime has a physical and material part as well: the artifacts, production processes, technologies, and infrastructures that are the embodiment of existing practices. The concept of the socio-technological regime offers an explanation why change is often so difficult to achieve. Actors involved in technological processes have difficulty in thinking outside the box because they are conditioned by existing conditions and ways of doing things. Furthermore, the existing technical infrastructure favors certain directions of new investments and innovations, making it hard for radically new technologies to fit in.

The highest level of the MLP is formed by the socio-technical landscape. It can be viewed as an exogenous environment that is not under the direct influence of the actors in the regime and niches. It includes macro-economic trends, deep cultural patterns, and demographic developments that only change at a very slow pace (hence the use of the term 'landscape'). For instance, the aging of a population has a deep impact on society but occurs at a very slow pace and is difficult to influence directly. The different levels of the MLP are defined by their degree of structuration. The higher the scale level the more aggregated the components and relationships between the actors and the slower the dynamics between them. New practices at the niche level can still easily change; however, at the level of the socio-technical regime this flexibility is already greatly diminished and at the landscape level changes may take years or even decades.

The MLP explains successful transitions through the interplay between the levels of niches, regimes, and landscapes. A breakthrough of a particular technology is often the result of one or more shocks or pressures at the landscape level. The resulting transition pathway depends on whether the niche is fully developed or not, and whether the relationship of the niche with the regime is competitive or symbiotic. In a classic paper in the transition literature, Geels and Schot[27] thus identified four transition pathways: 1) the transformation pathway is followed when niche-innovations are not yet fully developed and the regime is gradually adjusted in a symbiotic relationship with the niche, 2) the de-alignment/ re-alignment pathway where increasing landscape pressures on the regime leads regime actors to lose faith and the regime is dissolved. However, as niche innovations are not yet fully developed, several niches compete with each other until finally one wins out and forms a new regime. 3) the reconfiguration pathway occurs when the niche is fully developed and there is a symbiotic relationship between niche and regime that lead to further architectural changes in the regime, and finally 4) technological substitution ensues when the niche is fully developed and there is a competitive relationship which the niche innovation eventually wins. These four pathways are not mutually exclusive and shifts between pathways may occur leading to a sequence of different transition pathways. For instance Vandermeulen *et al.*[12] argue that the

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transition toward a bio-based economy in Flanders is likely to follow a typical sequence of pathways starting with a transformation pathway and evolving toward a technological substitution or de- and re-alignment pathway.

Bioclusters within the MLP

A biocluster is not a pure technological niche as defined in the MLP. Bioclusters often contain a mix of niche players and established regime actors and therefore McCauley and Stephens[40] argue that bioclusters take a position somewhere in between the niche and regime level. They conceptualize a biocluster not as a single niche but as the coordinator of a collection of niche activities in a region. According to this view a biocluster can be defined as a protected place where innovations are (temporarily) shielded from the mainstream selection pressures, nurtured through experimentation and learning, and eventually become empowered. This final form of empowerment can take two forms: 'fit and conform' versus 'stretch and transform.'[28,41] Innovations characterized as fit and conform only need temporary protection and support until they are sufficiently developed to compete within existing institutional frameworks. Innovations that stretch and transform aim to change the institutional context. These innovations do not aim to do the same things better, but to do better things as they refuse to accept the status quo as being unsustainable to begin with. In order to become successful, they need to change the existing institutional rules, regulations, and culture. This is a highly political process in which different innovation coalitions try to frame the public debate and where images, narratives, and discourses of the projected benefits and dangers of potential innovations play an important role.[42–44]

Looking at bioclusters through the lens of the MLP, it can be concluded that many innovations that are being developed within the context of the bioeconomy (e.g., biofuels, bioplastics, and pharmaceuticals) are designed to compete with existing fossil-based alternatives within the existing value chains (fit and conform). One of the reasons for the lack of stretch and transform niche dynamics in bioclusters might be the observation mentioned earlier in this section that regime players often have an important position within a biocluster. As McCauley and Stephens[40] hypothesize, bioclusters can both promote but also inhibit regime-level change. These concerns echo some of the objections of other authors who have been critical of general cluster policies and warn of the threat of established interests hijacking cluster policy for their own sectoral benefit.[18,45] The application of the MLP on bioclusters thus draws attention to the role of the established industries within bioclusters.

The role of power and politics in transitions has received an increasing amount of attention in the literature.[46,47] So far, cluster theory has neglected the role of power and politics in clusters. Although it has been acknowledged that governments can play an important role in the success or failure of establishing new cluster initiatives,[48–50] little attention has been paid to the strategies of bioclusters to influence policy and shape their institutional environment. In this regard the application of the MLP for the study of bioclusters is likely to provide an excellent opportunity to enrich this missing element of cluster theory.

Regional, sectoral, and technical innovation systems' perspectives

The third strain of frameworks for bioclusters is based on the national systems of innovation (NSI) perspective. The innovation system perspective provides an analytical framework to study technological change as a complex process of actions and interactions among a diverse set of actors engaged in generating, exchanging, and using knowledge.[51,52] The innovation system perspective broadens the view beyond business actors directly involved in innovation processes, to a multitude of actors that can play at role within innovation processes such as governments, NGOs, research institutes but also consultancies, banks, and consumer organizations. Secondly it pays particular attention to the influence of institutions (defined here as 'the rules of the game') as one of the factors that influence how the innovation game is played in different contexts. A popular notion in innovation systems research is the concept of failures. The innovation system approach has broadened the focus of market failures towards an analysis of other types of system failures that inhibit innovations.[6,53] The analysis of innovation systems investigates the quantity and quality of the structural components of an innovation system: the actors, networks, institutions, and infrastructure. When one of these components is insufficiently present or missing, the overall innovation system functioning is likely to suffer.[54] Innovation policy instruments can be categorized by the type of systemic problems that they are trying to solve – see Table 1. Weber and Rohracher[55] further expanded the failures framework with a new category of transformational failures. This approach looks at the entire system in its most aggregated form and asks whether it fulfils collective innovation priorities towards sustainable development and, if not, what prevents such processes of transformative change.[55,56]

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Table 1. Types of systemic problems and potential policies.

Potential systemic problems	Goals / solutions	Specific policy instruments suggested
Quantity and capability of actors	Stimulate participation of new actors and/or develop their capability	PPPs, interactive stakeholder workshops, innovation platforms, innovation labs
Quantity and intensity of interactions (network ties)	Stimulate occurrence of interactions, prevent too strong or too weak ties	Cooperative research programs, centers of excellence, collaboration and mobility schemes, debates facilitating decision making
Quantity and capacity of hard and soft institutions	Secure presence of hard and soft institutions and prevent too weak or too stringent application of rules	Awareness building measures: information campaigns; regulations, norms agreements, patent laws
Quantity and quality of physical, financial, and knowledge infrastructure	Stimulate and ensure adequate quality of physical, financial, and knowledge infrastructure	Taxes, loans, R&D grants, subsidies, public research labs; foresight studies

Source: Adapted from Wieczorek and Hekkert[54]

Different types of innovation systems can thus be distinguished based on different combinations of actors and institutional regimes. Both cluster theory and transition theory have incorporated innovation system thinking as a framework, albeit in different forms. Recent contributions to cluster theory come from the field of evolutionary economic geography, which focuses on the development of clusters from a perspective of regional and sectoral innovation systems.[57] In a similar fashion, transition theory has picked up thinking in innovation systems, especially technical innovation systems, as a new way of studying sustainability transitions.[58, 59]

The distinction between these different types of innovation systems is the way they draw the boundaries around the system components.[60] Regional and sectoral innovation systems are based on the idea that the conditions within different regions and within different economic sectors or industries influence the innovation process. Sectoral innovation systems are determined by the economic sector the agents are active in and the products and product groups that unify them.[61] National and regional innovation systems are delineated based on a spatial basis. Just like the NSI concept, a RIS is seen as a specific framework in which close inter-firm interactions, knowledge, and policy support infrastructures and socio-cultural and institutional environments serve to stimulate collective learning, continuous innovation, and entrepreneurial activity.[62] A difference with the national innovation systems approach is that, within the RIS approach, the term 'institutional thickness' is seen as an important characteristic that determines the successful development of the RIS. The term 'institutional thickness' refers to the formation of formal and informal networks that enhance the ability of actors to work together and share information locally.[63] Innovation systems that already host dynamic high-tech clusters and that offer essential conditions, such as excellent research institutes, venture capitalists, a pool of highly skilled mobile workers, and dense communication networks, have a high organizational thickness, whereas regional innovation systems in peripheral regions that are poorly endowed with such structures, experiences, and knowledge assets have low institutional thickness. Bioclusters have been promoted in peripheral regions with strong links to agriculture, forestry and/or the paper and pulp industry as a means to work on sustainable regional development.[10,64,65]

Within the field of evolutionary economic geography, there is a growing interest in how the institutional thickness of the RIS influences the development of clusters over time: cluster evolution.[57,66] Clusters are thought to have a separate life cycle that is independent of the product life cycle and industry life cycle.[67] Clusters have been conceptualized as having a number of distinct phases: emergence, growth, maturity, and decline.[68] Theoretical studies argue that the characteristics of a RIS influence the kind of cluster that is likely to emerge and the type of development path a cluster experiences.[69]

The third type of innovation system is the technical innovation system (TIS). In the TIS framework a specific technology provides the delineation of the innovation system. A technology can cut across different industrial sectors at the regional and national level.[70,71] A TIS thus transcends both the geographical boundaries of the RIS as well as sectoral delineations of the SIS. For instance, some typical technologies, like batteries, are manufactured in different regions and in different countries and are also in different sector ranging from consumer electronics and ICT to the transport sector as part of electronic cars.

The TIS approach has extended the literature on national and regional innovation systems beyond its focus on the

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Table 2. Technical innovation system functions.

	Function name and description	Examples
F1	Entrepreneurial activities: *Entrepreneurs transform the potential of new knowledge, networks, and markets into specific actions to generate new business opportunities.*	Participation in innovation projects Investments in new technology
F2	Knowledge development: *Knowledge development drives many new innovations. The results of knowledge development can take many forms – not only peer-reviewed papers but also the project reports and sometimes other tangible artifacts produced.*	Scientific research projects Scientific papers published Technical reports Patents New designs, maps, and prototypes
F3	Network formation and knowledge diffusion: *The knowledge network performs an important function in making information exchange easier. The more connections between actors within a network, the more easily knowledge is disseminated.*	Dissemination activities: workshops, courses, and training Information networks, platforms, and dedicated internet sites
F4	Guidance of search: *This function represents the selection function to facilitate a convergence in expectations about technological options.*	Shared vision documents Agreements and disagreements between partners and between partners and other actors Claims on behalf of or against a certain technology
F5	Market formation: *New technologies cannot outperform established ones. Often it is necessary to create (niche) markets, for instance, by measures that promote a demand for the new product.*	Subsidies and tax breaks Rules and regulations that directly affect certain production processes
F6	Resource mobilization: *Different kinds of investments are necessary for an innovation to develop (time, money, knowledge, etc.).*	Public and private sources and investments
F7	Support from advocacy coalitions: *The emergence of a new technology often leads to resistance from established actors. Actors need to raise a political lobby that counteracts this.*	Lobby activities Public pressure on actors to deal with a certain issue

Source: Adapted from Suurs and Hekkert[72] and Hekkert et al.[94]

static elements of actors, networks, institutions, and infrastructures, toward a dynamic view of innovation systems by looking at the activities (innovation functions) that have to be provided in a TIS in order for it to perform well – see Table 2. This dynamic view of innovation functions has been proven to provide fertile ground for the analysis of how certain sustainable technologies emerge and take off.[72,73] The innovation functions are not independent of each other but they interact. The way a certain function is fulfilled determines the way that other functions are being performed. In a positive scenario, certain functions develop alongside each other into an innovation motor: a virtuous cycle of functions constituted as a positive feedback loop through which momentum for change is built up and a new technology takes off.[72]

The analysis of bioclusters as regional, sectoral or technical innovation systems

Bioclusters can be placed on the intersection of sectoral, regional, and technical innovation systems – see Figure 1. A biocluster and an RIS are not necessarily the same thing. If we take the RIS as a geographical boundary, the RIS is broader than just the biocluster and it also encompasses other innovation activities within a region that do not belong to the bioeconomy. Some very large clusters can extend beyond the boundaries of the region and connect two or more regions with each other.

The sectoral approach focusses on the different economic sectors that are active within a biocluster. The range of economic sectors within a biocluster can be quite broad, including sectors like agriculture and forestry, green chemistry, pharmaceuticals but also textiles, paper and pulp, waste treatment, and recycling and biotech. However, even some economic sectors that do not traditionally specialize in production or processing of organic products and wastes, like ICT firms, can be part of a biocluster. Bioclusters thus can combine a number of very different SIS, and the particular combination depends on the geographical context and historical development paths of the region. An advantage of the SIS approach for bioclusters is that the focus on product groups in the sectoral innovation systems makes it relatively easy to use the standard statistical classifications of economic activities or

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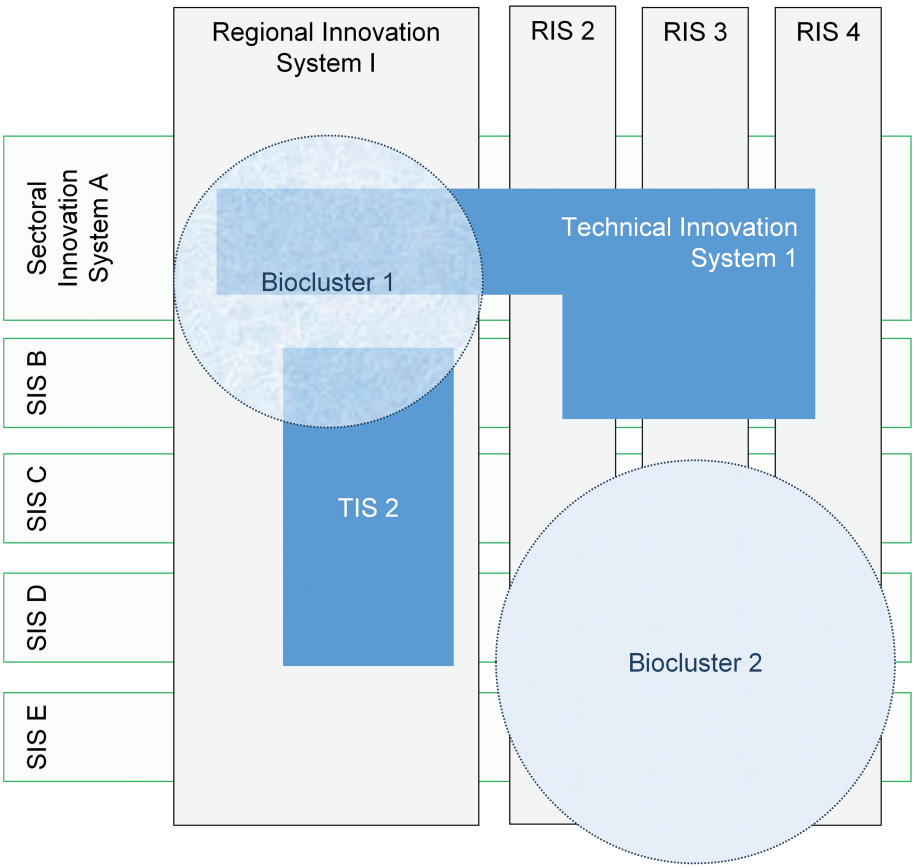

Figure 1. Delineation of bioclusters from a regional, sectoral and technological innovation system perspective (adapted from Markard and Truffer).[70]

industrial sectors (e.g., NACE for the EU, or ISIC for the UN) to track and analyze the developments within the SIS. A disadvantage, however, of applying the SIS perspective on bioclusters is that the replacement of fossil resources by biological ones requires that established sector boundaries and traditional value chains must eventually be crossed and a new economic sector must be established. The standard economic accounting methods on which the SIS perspective relies make it difficult to measure such a shift to these new economic sectors that are not yet formally recognized.

In this regard the TIS approach might be more helpful. The TIS approach has been developed specifically to follow how novel technologies that do not necessarily fall within the same sector, are being developed over time. A biocluster can combine a number of different TIS, and this makes it practically difficult to make a comprehensive study of a complete biocluster from a TIS perspective. This problem can be ameliorated by strategically selecting a number of TIS in a biocluster that offer the highest potential for sustainability transition. Eco-innovations are often defined as breakthrough innovations, or radical innovations that are new to the world and not only new to the region.[74,75] Focusing on a specific subsection of a biocluster offers inspiration to newly established bioclusters with regard to the different types of activities that have to be undertaken within a biocluster to develop itself.

The choice for the TIS, RIS or SIS frameworks can depend on the development stage of the particular biocluster. The TIS framework might offer the best opportunities to investigate the emergence, growth, and other dynamics of technology development within a biocluster. The RIS and SIS frameworks, on the other hand, are more suitable for the study of older, mature bioclusters that already have built up a specific knowledge base or are well tied in with the (inter)national knowledge networks. These frameworks assume a certain stability of the regional economic structure, which tends to emphasize the path dependency of regions. Regions are expected to build on their existing knowledge base because there is the assumption that there is only a limited mobility of organizations and the underlying infrastructure (laboratories, pilot plants).[75]

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Discussion and recommendations for further research

From this review it can be concluded that the MLP and the various forms of innovation systems offer good opportunities to study different aspects of bioclusters. At the same time the review has made it clear that all these frameworks give only a partial view. Bioclusters have some unique characteristics that make it difficult to apply these frameworks and some adaptations must be made to study their characteristics and their dynamics. This means that there is still some room for improvement and that the study of bioclusters can help to enrich both transition theory and cluster theory. In this final section some of these avenues for further research will be explored. The main research question is therefore turned around: not how can the study of bioclusters benefit from transition theory, but what can the study of bioclusters offer for the enrichment of transition theory?

The three following topics are of special interest with regard to the issues of sustainability transitions. (The list of potential interesting topics related to bioclusters is long and the following is therefore not intended as a comprehensive list.) The first topic is the issue of human agency. Transition theory struggles with the issue of agency because the contribution of individual decisions and actions remains hidden in many accounts of typical transitions[76] and insufficient attention is paid to the specific role that individuals play in transitions in the making.[77–79] Some of these roles consist of the way individuals contribute to innovations and knowledge development, reframe institutional rules and regulations through institutional entrepreneurship, and networking with other organizations through gatekeeping, bridging, and brokering.[80,81] This last issue is especially important in the case of biotechnology clusters, where the high-tech nature of innovation processes makes it impossible for a single organization to possess all the knowledge, skills, and financial resources to carry out the expensive R&D operations. Collaborations between small and large firms but also government agencies, venture capitalists and NGOs are not easy to achieve and an important question, therefore, is how the process of innovation orchestration between multiple actors takes place at the micro level in bioclusters.[82, 83]

A second, related, question is how the micro level interacts with various other scales and levels inside and outside bioclusters. Although it is acknowledged in transition theory that transitions are multilevel and multiscalar processes,[84,85] and that transition studies in general need to pay more attention to the spatial scale of transitions,[63,86] there have only been a few empirical studies so far. From the viewpoint of sustainable development, this is all the more important for bioclusters, because the mere use of biological resources does not automatically imply their sustainability. The heated debate about the sustainability effects of the promotion of different types of biofuels provides an important illustration in this regard.[87–89] The study of bioclusters, especially those bioclusters with a strong base in agriculture or forestry, provides an opportunity to study how the various effects of a cluster play out on these different scales and levels during the transition process. In this regard, the literature of socio-ecological transformations can provide inspiration for some of the relevant ecological and environmental scales in a more scale-sensitive approach of transition theory.[90, 91]

Finally there is the question of how biocluster development co-evolves with the context in which it is embedded. Trippl and Grillitsch[57] argue that more research is necessary to link the characteristics of a RIS to cluster evolution. Cluster evolution implies a more dynamic view of clusters and, although not completely new, this idea has only recently begun to receive more attention in the scientific literature.[57,66–68] The question is thus: 'How do different clusters evolve along different development paths depending on regional contexts?' The cluster life cycle only provides a simplified heuristic in this regard as, in reality, cluster development might follow different pathways.[92] From the perspective of transition theory, the question is how cluster development can be linked to different transition pathways. In this regard the mix of niche actors and regime actors in a typical biocluster offers new insights in the dynamics of the MLP. The new interest of some researchers involved in transition theory to apply computer models to study transitions[93] can help to combine the study of cluster evolution and transitions with each other.

Conclusion

Bioclusters stand out from other types of industrial clusters. The concept of a biocluster implies a focus not only on incremental innovations but also on radical innovations toward sustainability. So far, research on bioclusters is dominated by the general literature on the bioeconomy that focuses on innovation, employment, and competitiveness. However, in order to focus on the sustainable development part that the bioeconomy promises, transition theory can add a new perspective to the study of bioclusters.

From the review of transition frameworks, it can be concluded that the choice of a particular framework for

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the study of bioclusters depends on the specific underlying patterns and mechanisms in which one is interested. The MLP is helpful to offer a new perspective through the niche internal processes and focus on the role of power and politics within bioclusters, while the approach of the SIS and RIS is useful to study how the knowledge base of established bioclusters evolves. The TIS approach provides helpful tools to examine the dynamics of newly established bioclusters focussing on radical environmental innovations.

The study of bioclusters offers an interesting opportunity to combine cluster theory and transition theory with each other. Three topics are of special interest in this regard. The first is the need for more attention to the micro-level of bioclusters and the importance of human agency in the development of a biocluster. The second is the need for a multiscalar perspective of the interactions of bioclusters across geographical, environmental, and administrative scales. The third is the link between cluster development pathways and transition pathways.

Acknowledgements

This study was financed through the TRAFOBIT project 'The Role and Functions of Bioclusters in the Transition to a Bioeconomy' (031B0020) under the call 'Bioökonomie als gesellschaftlicher Wandel' of the German Federal Ministry of Education and Research (BMBF). The author would like to thank Lars Coenen for his comments on an early draft of the paper.

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