Technological innovations and sustainability transitions in the bioeconomy:
A multiscalar approach toward the development of bioclusters

Dissertation

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Executive summary

The bioeconomy is expected to deliver key solutions to some of the urgent sustainability challenges, such as the climate change, resource scarcity, loss of biodiversity, and world hunger. By coupling economic development with a strong environmental perspective, the bioeconomy holds a promise to policy makers, industry actors, and society to deliver key benefits that are consistent with the principles of sustainability.

To study the bioeconomy I examine bioclusters which are geographic concentrations of industrial activities and various processes related to the bioeconomy. Bioclusters provide fertile ground for advancing both sustainability transitions and technological innovations in the bioeconomy due to the synergies in the use of natural resources and new technological knowledge. Bioclusters, while being local, are in a constant interplay with the world surrounding them: they therefore have multiscalar properties. According to the literature on sustainability transitions, innovation- and sustainability-related outcomes can be explained by the various factors that interrelate the studied place of transition with its wider context. In case of bioclusters, these interrelations can take different forms: from the local alignment with the broader institutional and administrative frameworks to the local involvement in the global resources flows, such as investments and knowledge. I therefore adopt a multiscalar perspective toward the development of bioclusters by interpreting the idea of scale along different meanings beyond its mere geographical perception. This framework text (*Rahmentext*) provides the conceptual basis for the application of scales and principles of multiscalarity to bioclusters by combining concepts and insights from different scientific fields, such as sustainability transitions, socio-ecological systems, and technological innovation systems.

The empirical investigation relies on different methodologies and research designs in order to both develop and apply theoretical frameworks. I employ the method of quantitative meta-analysis to develop a multiscalar framework for studying bioclusters. I then apply this framework to examine the ecological development of the Bazancourt-Pomacle biocluster in France, using the method of qualitative event-history analysis. This method is also used to study the technological development of the biocluster by applying an existing framework from the field of technological innovation systems. The studies were conducted using various data sources, including bibliometric data, expert interviews, participatory observations, as well as document and news analysis. The results are reported in the three research papers that make up this cumulative dissertation.

The dissertation enriches the existing literature on sustainability transitions, technological innovation systems, and their geographies. It highlights how adopting a broad perspective on scale and scale dynamics leads to a more nuanced understanding of bioclusters' role in the bioeconomy transition. In particular, the study reveals how the interrelations among different scales and levels can lead to positive sustainability outcomes in bioclusters. It also highlights the

multiscalar constellations and dynamics of resources within a new local perspective on technological innovation systems.

These insights expand the range of tools for managers and policy makers aiming to drive sustainability transitions and technological innovations in the bioeconomy. The sustainability of bioclusters is interpreted as not directly controllable by policy, but rather as a posteriori benefit resulting from various conditions that, in turn, are more amenable to policy interventions. Promoting the technological innovations in bioclusters is better realized by stimulating the formation of biocluster-internal markets and disseminating the legitimacy of biorefining technologies at broader geographical levels.

Acknowledgements

> “The economy is a wholly owned subsidiary of the environment, not the other way around.”
>
> *Gaylord Nelson*[i]

I would like to express my sincere gratitude to the people whose support and encouragement made it possible for me to write this dissertation.

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[i] American politician and environmentalist who is best known for founding Earth Day, an annual event celebrated worldwide on April 22nd to raise awareness of environmental issues.

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List of abbreviations

BPC	Bazancourt-Pomacle Cluster
BRTIS	Biorefining Technological Innovation System
EHA	Event-History Analysis
EU	European Union
NGO	Non-Governmental Organization
PEFC	Programme for the Endorsement of Forest Certification
R&D	Research and Development
SBP	Sustainable Biomass Program
SES	Socio-Ecological Systems
TIS	Technological Innovation System

Preface and list of publications

This PhD thesis consists of three research papers that are either published or under review in peer-reviewed journals. Below, I present the general introduction and reflection (*Rahmentext*) which serves as the fundamental framework that guides and shapes the entire scope of this thesis. This *Rahmentext* describes the conceptual and empirical backgrounds, methodologies, and the research approach of my thesis. It also provides brief outlines of the research papers and reflects upon their implications for theory and practice.

The three research papers have been published or submitted in the following order:

- Ayrapetyan, David & Hermans, Frans (2020). Introducing a multiscalar framework for biocluster research: A meta-analysis. *Sustainability*, 12(9), 3890. https://doi.org/10.3390/su12093890.

- Ayrapetyan, David; Befort, Nicolas & Hermans, Frans (2022). The role of sustainability in the emergence and evolution of bioeconomy clusters: An application of a multiscalar framework. *Journal of Cleaner Production*, 376, 134306. https://doi.org/10.1016/j.jclepro.2022.134306.

- Ayrapetyan, David; Befort, Nicolas & Hermans, Frans (2023). From local markets to global legitimacy: A bottom-up perspective on technological innovation system's dynamic. Under review in: *Research Policy*.

I have written these research papers and the *Rahmentext* in the period between March 2018 and April 2023 while I was employed as a research associate at the Leibniz Institute of Agricultural Development in Transition Economies (IAMO) and as a PhD student at the Faculty of Law and Economics, Department of Economics of the Martin-Luther-University Halle-Wittenberg. The dissertation constitutes a research output of the TRAFOBIT project (the role and functions of bioclusters in the transition to a bioeconomy) financed by the Federal Ministry of Education and Research (BMBF) in Germany under grant 031B0020.

1. Introduction

Following a substantial decline during the first year of the COVID-19 pandemic, the global anthropogenic CO_2 emissions rebounded by 4.8% in 2021 and continue to increase (Friedlingstein et al., 2022; Liu et al., 2022). Human activity, described by an increasing use of fossil fuels, such as coal, natural gas, and oil, continues to have detrimental consequences on the environment and the ecology, rendering the urgency of a transition to a sustainable economy increasingly apparent. Russia's invasion of Ukraine in 2022 and the resulting international energy sanctions have opened yet another dimension to this urgency, prompting many countries in the European Union to seek independence from fossil resources not only in the environmental, but also in the geopolitical landscape (European Commission, 2022).

The bioeconomy has been envisaged as an alternative economic system that would not put pressure on the environment and reduce the dependence of economies on fossil resources (Georgescu-Roegen, 1978; El-Chichakli et al., 2016). The concept of the bioeconomy has increasingly grown in popularity, both in science and policy fields, as a potential way of organizing production and consumption practices in the society in a more sustainable way that incorporates exclusively renewable biological resources (McCormick & Kautto, 2013). In this way, the bioeconomy implies the substitution of inputs from fossil sources with inputs from renewable nature sources. Such a substitution can entail substantial changes in many economic and industrial sectors that currently depend on the intensive consumption of fossil resources. The bioeconomy can help in addressing sustainability challenges, such as the scarcity of natural resources, environmental pollution and climate change, by decreasing the dependence on fossil fuels, better waste and water management and reduced greenhouse gas emissions. Apart from reducing the dependence on fossil resources, the bioeconomy also promises new economic opportunities, such as formation of new businesses, increased resource efficiency, economic resilience, and job creation in new scientific sectors dealing with the research into new crops and new applications of biomass (BECOTEPS, 2011; Brunori, 2013).

Table 1. Bioeconomy sectors and their activities

Source: D'Adamo et al. (2020), Imperial College London (2015)

Bioeconomy sector	Activities included
1. Primary biomass production	Agricultural crops, livestock, horticulture, aquaculture, forestry
2. Food and feed	Human food, beverages, tobacco, animal feed
3. Construction	Bio-based fibers, building materials, timber, furniture
4. Chemicals and polymers	Bio-based chemicals, pharmaceuticals, enzymes, new molecules for cosmetics and household products
5. Pulp and paper	Paper, fibers
6. Textile and clothing	Clothes, shoes
7. Energy	Biofuels, bioelectricity, gaseous energy
8. R&D services	Knowledge development through R&D in the bioeconomy

The principles of the bioeconomy can be implemented in many sectors which can partially or completely transition to the use of renewable natural resources. Table 1 presents a list of eight bioeconomy sectors and their activities. Traditional agricultural activities, such as the cultivation of crops, livestock rearing, aquaculture, horticulture, beekeeping, fall under the definition of the bioeconomy, since they are described by the production and use of renewable biological resources. However, current political, societal, and scientific narratives of the bioeconomy mostly focus on a different vision for the bioeconomy. This vision primarily constitutes a bioeconomy described by the production of advanced, bio-based products in different sectors that have so far been major consumers of fossil resources (European Commission, 2018).

Industrial activities in the field of the bioeconomy tend to concentrate in specific regions and localities (Zechendorf, 2011), forming bioeconomy clusters: bioclusters for short. They are used by the governments to strengthen the synergies and collaboration between different bioeconomy actors leading to positive sustainability- and innovation-related outcomes (Hermans, 2021).

In this dissertation, I investigate how bioclusters can contribute to technological innovations and sustainability in the bioeconomy. I will do this by applying a multidisciplinary perspective that is derived from three main theoretical components: the study of sustainability transitions (Markard et al., 2012; Köhler et al., 2019), the study of technological innovation systems, or TIS (Carlsson & Stankiewicz, 1991; Markard et al., 2015), and the theory of Socio-Ecological Systems (SES) (Gunderson & Holling, 2002; Walker et al., 2006).

From the perspective of sustainability transition, bioclusters can be viewed as a specific type of sustainability-oriented clusters that can maintain sustainable interaction between the ecology and economy by creating local, short-distance value chains of renewable natural resources (Ehrenfeld, 1997; Deutz & Gibbs, 2008; Bosman & Rotmans, 2016). However, the mere fact of using renewable natural resources does not automatically imply sustainability. Whether bioclusters are sustainable or not depends on a complex interplay of geographical, institutional, structural, and sustainability aspects. The literature on socio-ecological systems (SES) interprets all these aspects as scales and argues that the dynamics among these scales can explain positive or negative sustainability outcomes (Cash et al., 2006; Walker et al., 2006; Ostrom, 2009). While multiscalar thinking can advance our understanding of transitions, insights on how multiscalar processes drive transition through bioclusters are still lacking.

From the perspective of technological innovations, bioclusters can be viewed as a specific local type of Technological Innovation Systems (TIS) focused on biorefining technology. According to the TIS literature, actors need different TIS-specific resources in order to conduct their innovation activities (Binz & Truffer, 2017; Rohe, 2020). TIS resources, such as knowledge, investments, markets, and legitimacy, are important for bioclusters that represent features of local biorefining TISs. However, in contrast to natural resources that can be sourced locally, bioclusters need to source TIS-specific resources from broader geographical levels, such as regional, national, and global. The TIS literature has studied the spatial embeddedness and dynamics of the TIS resources along regional, national, and global geographical levels. Yet, there have been no attempts to conceptualize TISs locally and study the dynamics and interplay of multiscalar TIS resource constellations from a primarily local perspective.

Understanding how local bioclusters develop along both ecological and technological domains will therefore enrich the literature on sustainability transitions, technological innovation systems, and their geographies, as well as help managers and policy makers in devising locally tailored practices and policies for promoting ecological and technological development in bioclusters.

This dissertation, therefore has the aim to investigate how bioclusters can contribute to technological innovations and sustainability transition in the bioeconomy. To achieve this aim, I apply a multiscalar approach designed to account for the different factors, processes, and resource flows that together drive the ecological and technological development in bioclusters. By applying different methodologies in different research contexts, this dissertation both develops and applies theoretical frameworks to answer its research questions. In the remainder of this *Rahmentext*, I engage with the theoretical and empirical background relevant for this investigation.

In Chapter 2, I introduce the concept of clusters and their advantages as they relate to innovativeness, learning, and technological development. I end the chapter by presenting and defining a specific type of clusters in the field of the bioeconomy, i.e. bioclusters, which offer not only the advantages associated with conventional clusters, but also advantages related to sustainability and sustainable development.

In Chapter 3, I delve further into the role bioclusters play in the bioeconomy by developing it along the ecological and technological domains. The contribution of bioclusters to these two domains is explained primarily by their potential to concentrate processes related both to sustainability transition and technological innovation in one locality. I use this feature of bioclusters to argue in favor of a multiscalar approach toward studying their development. Combining ideas and concepts from the literature on sustainability transitions and socio-ecological systems, I argue for a broader understanding of scale that extends beyond its mere geographical perception. I describe how studying the dynamics along multiple geographical, institutional, structural, and sustainability scales can further our understanding of the ecological and technological development in bioclusters.

Chapter 4 draws the overarching research question of this dissertation and recapitulates the research gaps from the previous chapter in order to formulate three specific research questions, each addressed in one research paper of this dissertation.

In Chapter 5, I illustrate the methodological approach of this thesis. There I present the methods and research contexts used in relation to each of the research questions that are linked to the two research domains, i.e. the ecological and technological development in the bioeconomy. At the end of the chapter, I outline some limitations of the methodological approach.

In Chapter 6, I present the overviews of the individual research papers that are either published or under review in peer-reviewed journals. There I also provide short summaries of the research papers by outlining their research aims, methods, and main results.

Finally, in Chapter 7, I summarize the theoretical and practical implications of the results of the three research papers. I show how the results fit into and enrich the existing theoretical literature as well as outline the lessons and recommendations for practitioners, managers, and policy makers.

Overall, the dissertation brings valuable new insights into the literature on sustainability transitions, technological innovation systems, and their geographies. It highlights how adopting a broad perspective on scale and scale dynamics leads to a more nuanced understanding regarding the contribution of local bioclusters to the global system of bioeconomy transition. The research provides valuable insights for managers and policy makers interested in promoting the ecological and technological development in the bioeconomy as well as in the broader field of renewable energy technologies. Bearing in mind the important role that localities and clustered networks of actors play in the development of sustainable technologies, our results yield locally-tailored recommendations for managers and policy makers that would enable them to design more informed and efficient intervention strategies serving the purpose of mitigating the climate crisis.

2. Clusters and bioclusters

2.1. The concept of clusters and their advantages

The idea of "industrial districts" introduced by Alfred Marshall in the early 1890s built the foundation for studies of economic activities distributed unevenly across space and concentrating in specific localities and regions. Further studies, in particular by Krugman (1991, 1998), dived deeper into the economics of the natural agglomeration processes of firms and industries. Alternatively, Michael Porter popularized the idea of clusters as agglomerations of industrial activities, stemming from government interventions. In his work, Porter (1990) argued that geographical clustering reinforces the dynamics among four key elements of industrial activity: (1) factor conditions, (2) demand conditions, (3) firm strategy, structure and rivalry, and (4) related and supporting industries. More intense dynamic among these four elements, conceptualized as Porter's diamond, was associated with increased productivity and economic performance of clustered firms. Therefore, creating industrial clusters through policy measures appeared as a means to strengthen growth and economic competitiveness of countries.

In his later work, Porter (1998) defined a cluster as "[…] a geographically proximate group of interconnected companies and associated institutions in a particular field, linked by commonalities and complementarities", thus extending the scope of possible cluster actors to include not only industrial firms, but also different associated organization, such as research institutes, universities, public bodies, media, and organizations for collaboration (Fig. 1). These organizations are meant to promote the innovativeness of firms by providing (access to) different resources, such as new knowledge and financing. Their mission is also to support the industry by facilitating its legitimacy and market access – two factors that are often treated as resources of a particular immaterial type crucial for firms' innovation performance (Binz et al., 2016; Rohe, 2020).

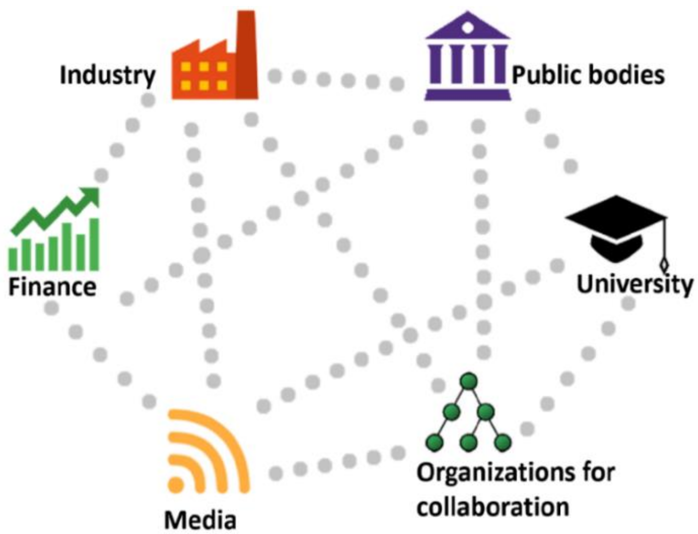

Figure 1. Actors and their connections in a cluster
Source: Sölvell (2009, p. 16)

Clusters are used by governments to promote innovations and development in particular industries and technological fields. The feature of geographic proximity of clusters – often leading to clusters operating in particular sub-regional, i.e. local contexts – creates various advantages for firms. Being geographically localized allows firms to reduce their transaction costs (Cantner et al., 2013) and increase productivity (Brakman & van Marrewijk, 2013). The success of the businesses in clusters depends on frequent face-to-face contacts that can be even more important than the application of modern communication technologies. Spatial proximity favors higher innovative output, profitability, and productivity (Cooke, 2001; Cantner et al., 2013), as well as mutual trust and social proximity among actors (Boschma, 2005).

2.2. Cluster life-cycles

Clusters develop gradually and can go through different development stages. The number of the development stages as well as their naming are different across studies. Nevertheless, most of them assume a general pattern of growth at the beginning, sustainment, and decline at the end. For instance, Bergman (2008) differentiates between the existence phase, expansion phase and exhaustion phase with the two latter having additional sub-phases, namely, exploratory expansion and exploitative expansion as sub-phases for the expansion phase and lock-in and renaissance as constituents of the exhaustion phase. Avnimelech et al. (2008) takes a more sector-specific approach to outline the phases of pre-emergence, emergence, restructuring and consolidation to describe the development path of a high-tech cluster in Israel. However, the most commonly-applied classification is that of Menzel and Fornahl (2010) who proposed four stages of a cluster life cycle that are deemed to be relevant for the most types of clusters. These stages are: emergence, growth, sustainment and decline (Fig. 2).

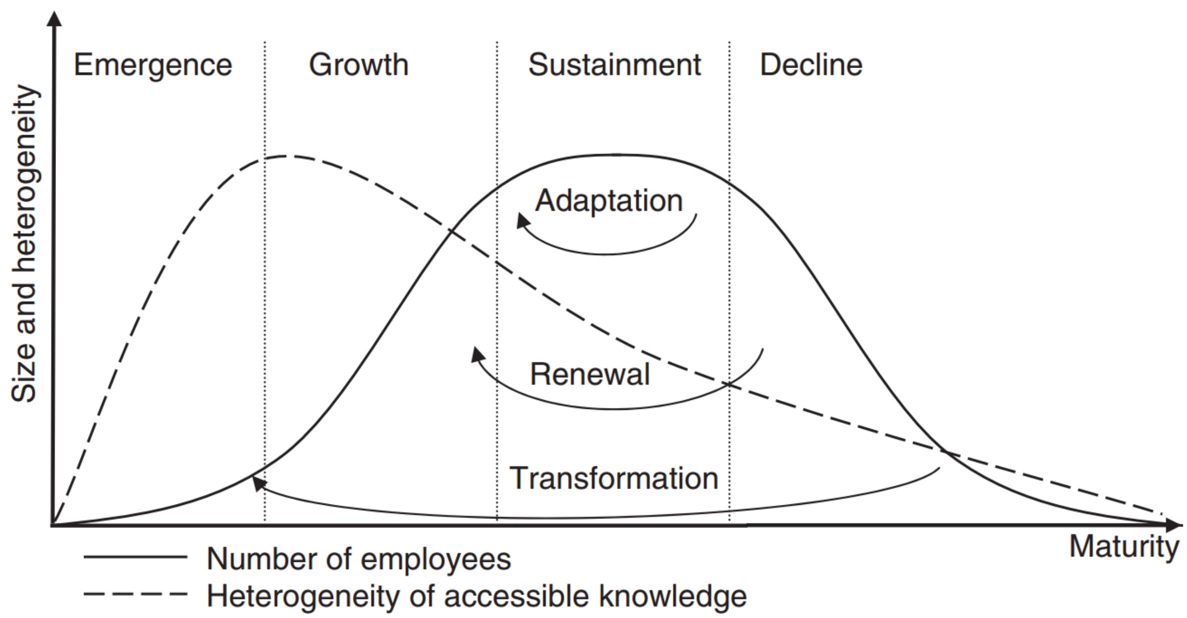

Figure 2. Four stages of the cluster life cycle
Source: Menzel and Fornahl (2010)

In the emergence phase, Menzel and Fornahl argue that clusters are very difficult to identify because of the low number of firms. However, the start-ups are quite intense at this phase. The firms that make up the cluster at this stage have heterogeneous technological backgrounds resulting in few possibilities for cooperation. Nevertheless, an emerging cluster can be identified by the strong vision of the technological direction and the endowment with certain input factors, such as strong scientific base, abundance of natural resources, or particular industrial traditions in the region. The phase of growth makes the cluster more visible with definable boundaries. Existing companies actively grow in size and also attract new start-ups. Due to the intense cooperation and mutual learning, the technological orientation of the firms converges toward a focal trajectory that forces the technological heterogeneity of the cluster to decline. During the sustainment phase the cluster shows neither a high growth compared to the industry nor a significant change in the number of companies. A dense and established network of the actors makes the cluster's technological trajectory focus further. Finally, the decline phase is characterized by a decreasing number of companies and employees. The innovation rates can still remain high in a declining cluster. However, those innovations take place within the exhausted technological path and in a locked-in state in which the few innovative firms cooperate mostly among each other and rarely establish links to external actors. The phase of decline can lead either to a loss of innovative capacity of the cluster, or to a renewal of the cluster.

The life cycle model should not be interpreted as a deterministic progression sequence which all clusters follow (Martin & Sunley, 2011). Instead, clusters can have different development pathways and maintain a certain size. Therefore, following Frenken et al. (2015), we interpret the cluster life cycle model of Menzel and Fornahl as a heuristic device to structure the development path of a cluster in the field of the bioeconomy.

2.3. Clusters in the bioeconomy

The tendency of clustering of firms and industries relates to the bioeconomy as well. The key bioeconomy actors, which can include farmers, industrial firms, research organizations, as well as regional universities and public bodies, cooperate closely in bioclusters. Building upon the cluster definition of Porter (1998), we define bioclusters as specific types of sustainability-oriented clusters that constitute geographically proximate and interconnected firms and organizations specializing in various fields of bioeconomy. In addition to appropriating the benefits traditionally associated with clusters, such as enhanced learning, competitiveness, entrepreneurship, innovation, and mutual trust (Boschma, 2005), the role of bioclusters in the bioeconomy transition is explained also by the additional goal of sustainability. Bioclusters have the potential to localize the production and processing of natural resources (Ehrenfeld, 1997; Deutz & Gibbs, 2008), resulting in possible sustainability gains in their localities and surrounding regions (Lehtoranta et al., 2011; Bosman & Rotmans, 2016; Hermans, 2021). Many governments currently pursue strategies and policies supporting bioclusters (Zechendorf, 2011; Kircher, 2012; Haarich et al., 2017) in order to utilize their innovation- and sustainability-related advantages.

In the next chapter, I dive deeper into the role that bioclusters play in driving sustainability transitions and technological innovations. Integrating concepts and ideas from the fields of sustainability transitions and socio-ecological systems, I advocate for a multiscalar approach toward studying the ecological and technological development in bioclusters.

3. Sustainability transitions and technological innovations in bioclusters

Bioclusters can be viewed as concentration of two important process fields: sustainability transitions and technological innovations. Being local phenomena, bioclusters contribute to these fields by creating various dynamics and interrelations with the world surrounding them. The first category of these interrelations are the processes through which bioclusters contribute to the bioeconomy and sustainability transition. The second category of these interrelations are the processes through which bioclusters drive knowledge development and technological innovations in the bioeconomy. I proceed along these two categories because they represent the two main expectations of bioeconomy in general and bioclusters in particular: the transition to a more environmentally-friendly economy, and the promotion of technological innovations and valorization of scientific knowledge (Bugge et al., 2016; Hermans, 2018).

3.1. Ecological development in bioclusters

Bioclusters are expected to play an important role in the transition toward a bioeconomy (Zechendorf, 2011; Hermans, 2018; Stegmann et al., 2020). They are the hubs of bioeconomy activities where renewable biological resources are being processed and transformed into different value-added products. The expectations of sustainable ecological development in bioclusters come from their potential to establish short-distance value chains of natural resource supply – often within one region – and also from their potential to engage in local exchange of these resources, their by-products, and waste streams according to the principles of industrial ecology (Chertow, 2000). Applying these principles in bioclusters can have positive effects on sustainability, such as reduced CO_2 emissions, and more sustainable use of soil, water, and wood resources. For example, a biocluster in the agro-industrial sector of the bioeconomy can achieve reduced CO_2 emissions by incorporating biofuels, converting CO_2 into a resource for other firms, as well as by cultivating crops that capture CO_2 from the atmosphere. Soil sustainability can be improved through improved crop rotation, reduction of pesticide use, and cultivation of beneficial crops that protect the soil from erosion. Bioclusters can also improve wood sustainability by achieving certain certifications, such as Programme for the Endorsement of Forest Certification (PEFC) or Sustainable Biomass Partnership (SBP).

Achieving such positive sustainability effects can play an important role in bioeconomy transition. However, using renewable natural resources per se does not automatically imply sustainability. Bioeconomy activities in bioclusters can have adverse sustainability effects at various geographical levels, including other countries and continents (Maya-Ambia, 2011; Hermans, 2018; Asada et al., 2020; Stegmann et al., 2020). These effects, as illustrated most dramatically by the production of first-generation biofuels, can occur unexpectedly in different parts of the world (Liu et al., 2013). The acquisition of agricultural lands of developing countries in the Global South by more developed countries in the Global North for the production of biofuel feedstocks had massive sustainability consequences for soil, water, and biodiversity, especially if these new agricultural lands were replacing existing rain forests (Priefer et al., 2017). In addition, this put in danger the agricultural possessions and livelihoods of local farmers (Van Eijck & Romijn, 2009; Oberlack et al., 2018). More recently, the sustainability effects of the globalization of the forestry and industrial agriculture – both on the supply side of the bioeconomy – have also been interpreted within the concept of extractivism, as the latter has expanded to include these sectors as well, beyond the conventional fossil fuel and mining extractivism (Covarrubias & Raju, 2020; Chagnon et al., 2022). Bioeconomy activities can deepen extractivist practices by depleting soil leading to intensified use of fertilizers and pesticides that ultimately contaminate the ecosystems and cause negative sustainability effects (Tittor, 2021). Therefore, the potential sustainability trade-offs of bioclusters (Stegmann et al., 2020), wherever they may come into play, are important to account in discussions about the sustainability of bioclusters.

Ecological development in bioclusters, as well as in general, is a complex issue. Attempts to improve sustainability along different indicators and across various geographical levels have often led to disappointing results among policy makers, managers, and society (Cash et al., 2006). The challenges lie primarily in the fact that sustainability involves multiple aspects that are interconnected at various geographical levels, such as local, regional, national, international, and global. The literature on sustainability transitions (Markard et al., 2012; Hansen & Coenen, 2015) argues that there are a number of factors that can explain why transitions occur in one place and not in the other. These factors, such as institutional and political structures, natural resource endowment, social and historical traditions, as well as availability of financial, knowledge, and human resources (Hansen & Coenen, 2015; Truffer et al., 2015; Köhler et al., 2019), play a decisive role in the speed, direction, and extent of sustainability transitions in different locations. It is difficult to consider all these different aspects as well as their interconnections together, while engaging in policy making and management of sustainability issues. As a result, some bioclusters succeed to pursue ecological development and sustainability transition (e.g. Auer et al. (2016); Branco and Lopes (2018); Morales (2020)) while others cause adverse sustainability effects for the environment and the society (e.g. Maya-Ambia (2011); Weiss et al. (2017)). All in all, there is currently a lack of awareness about how bioclusters contribute to sustainability. While the field of sustainability transitions advocates for a multiscalar geographical approach to understand transition processes, a better understanding of how bioclusters become more sustainable requires a stronger emphasis on the idea of the scale that extends beyond its mere geographical perception.

3.2. Multiscalar approach toward the ecological development of bioclusters

To understand how bioclusters pursue ecological development and contribute to sustainability, we adopt the multiscalar perspective in sustainability transitions while augmenting it with the way of theorizing multiscalarity in the field of socio-ecological systems (Gunderson & Holling, 2002; Walker et al., 2006). In this field, the concepts of scales and multiscalarity have been used specifically in issues dealing with sustainability (Cash et al., 2006; Ostrom, 2009; Olsson et al., 2014). Socio-ecological systems (SES) engage with the complexity of human-environment dynamics across various sociological and ecological scales. According to Cumming et al. (2006), ecological scales refer to spatial and temporal aspects of processes, whereas sociological scales are used to study social structures, such as institutions, cultural norms, as well as interpersonal and interorganizational relations. The rationale for multiscalar thinking in SESs is that sustainability issues are not confined to a single scale or level, but instead should be represented and analyzed along different scales and levels (Gibson et al., 2000; Vervoort et al., 2012; Hebinck et al., 2021).

The existence of different scales and levels is explained by the way how the modern society is structured. People make decisions on different hierarchy levels, follow rules of various institutional power, engage in cooperative behaviors that require different levels of personal and organizational involvement, and exhibit different levels of trust in their relations. We can see that for many aspects we engage with, there are different levels representing this aspect, and these levels vary by magnitude. Fig. 3 illustrates four scales that are often used in studies on socio-ecological systems.

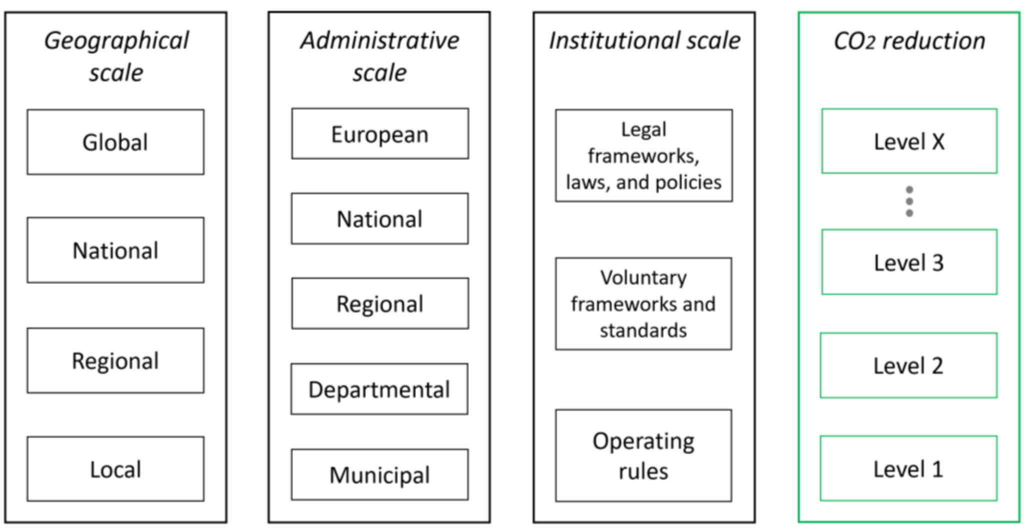

Figure 3. Illustration of geographical, administrative, institutional, and CO_2 reduction scales and their associated levels

Source: adapted based on Gibson et al. (2000); Schut et al. (2013); Hermans et al. (2016); Stegmann et al. (2020)

The most commonly used scale both in sustainability transitions and socio-ecological systems is the **geographical scale** (Gibson et al., 2000; Cash et al., 2006; Raven et al., 2012; Hermans et al., 2016). It is designed to measure the spatial extent of events and processes. The levels on the geographical scale denote the exact specification of the territorial boundaries: these usually range from local up to the global level. For bioclusters, this scale is relevant to measure the various resource flows because a local biocluster can source its resources from regional, national, or even global levels. This means that depending on the scope of the study, the geographical scale can represent various processes that adhere to the logic of the geographical scale (see Section 3.4). The **administrative scale** represents the administrative divisions of the respective government levels (Schut et al., 2013) that can provide legislative incentives and financial support for the biocluster. It is somewhat similar to the geographical scale, however the levels on the administrative scale can be different depending on the administrative territorial division in a particular country. The **institutional scale** reflects the degree of formalization of rules and laws ranging from informal norms of conduct, to more formal frameworks and standards, up to highly formalized laws and policies (Hermans et al., 2016). A biocluster can incorporate one or more types of these rules, depending on its development stage, management structure, and historical background. The last scale illustrated on Fig. 3 is the scale of **CO_2 reduction**. This is an example of a sustainability scale because it measures a particular indicator that is important to consider in trying to improve the sustainability performance of a biocluster. Unlike the first three scales, the levels on the scale of CO_2 reduction are unspecified and can show numbers, indicating the amount of saved CO_2 emissions.

The scales presented on Fig. 3 are likely to be relevant for studying sustainability issues because they represent important geographical, institutional and sustainability measures that are relevant for a broad range of phenomena related to sustainable development (Cash et al., 2006). However, a thorough understanding of how *bioclusters* contribute to ecological development requires to consider scales that are specific for bioclusters. There is no single multiscalar framework that would be applicable for any system working toward sustainability because different disciplines operate with different concepts and scales (Ostrom, 2009; Schut et al., 2013; Ostrom, 2019). Olsson et al. (2014) argue that in order to ensure a better management of sustainability issues, the social, technological, and ecological scales, as well as their interrelations need to be studied simultaneously and that respective frameworks are needed. Even though bioclusters have been quite popular among policy makers in the recent decade as a potential means for creating a more sustainable economy, there has been no framework to analyze the different scales and their interrelation in bioclusters. Therefore, in order to analyze the ecological development in a biocluster from a multiscalar perspective, it is first necessary to develop a framework that would integrate the geographical, institutional, structural, and sustainability scales that are specific for bioclusters. Having such a framework, it would be possible to apply it to a particular biocluster and study its sustainability outcomes in the context of their interrelations with other scales.

The field of SES interprets sustainability outcomes, whether positive or negative, as a result of processes evolving along a multitude of scales that represent the geographical, institutional, political, social, and other aspects of the studied phenomenon. According to Kok and Veldkamp (2011) and Buizer et al. (2011), achieving certain outcomes at one scale may be possible only by making changes at other scales and levels. With regard to sustainability, Ostrom (2009) and Olsson et al. (2014) stress that the interrelations among various scales and levels can explain the sustainability outcomes in SESs. Sustainability outcomes in bioclusters can therefore be understood by studying how the interactions among various geographical, institutional, and structural scales ultimately lead to changes in various sustainability scales. While having a multiscalar framework would offer a *set of scales* relevant for bioclusters, studying their sustainability outcomes would require to make a strong emphasis on the *interactions among scales* that comprise the multiscalar framework. There are two types of multiscalar interactions conceptualized in the literature on socio-ecological systems (Gibson et al., 2000). The first are cross-scale interactions implying an interaction between two levels of two different scales. The second are cross level interactions that imply an interaction between two levels of the same scale. Studying how a biocluster contributes to sustainability would therefore require to analyze how the different cross-level and cross-scale interactions among geographical, institutional, and structural scales lead to changes along specific sustainability scales.

3.3. Technological development in bioclusters

Technological development plays an essential role in advancing our potential to address global sustainability challenges, such as global warming, waste management, and environmental pollution (Kuhlmann & Rip, 2018; Malhotra et al., 2019). Promoting technological development and innovations in the bioeconomy can help to deliver a broader range of possible applications of bio-resources in the economy, increasing thus the scale of bioeconomy while simultaneously balancing it with the sustainability aspect (Pfau et al., 2014).

Advanced knowledge-based biorefineries that host one or more technologies of biorefining play a crucial role in the technological development in the bioeconomy (Bauer et al., 2017; Bauer et al., 2018). The development and diffusion of sustainable technologies in general and biorefining technology in particular has often been studied through the lens of Technological Innovation System's framework (Carlsson & Stankiewicz, 1991; Markard et al., 2015).

3.3.1. The framework of Technological Innovation Systems (TIS)

The TIS framework originated from the theory of evolutionary economics (Winter & Nelson, 1982). Along with the related national (Lundvall, 1988), regional (Cooke et al., 1997), and sectoral (Malerba, 2002) delineations of innovation systems, the TIS approach is designed to study innovation dynamics within the limits of a particular technology (Markard et al., 2015). A TIS is defined by Carlsson and Stankiewicz (1991, p. 93) as "[…] a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology." Four elements are therefore present in any TIS: technology, actors, networks, and institutions (Jacobsson & Bergek, 2011).

Hekkert et al. (2007) and Bergek et al. (2008a) refined the TIS concept by introducing the notion of TIS functions. These functions are understood primarily as the key processes taking place in a TIS and serving its purpose of developing, diffusing, and utilizing technology. Table 2 presents and describes seven functions of TISs.

Table 2. The seven functions of technological innovation systems
Source: adapted based on Hekkert et al. (2007); Bergek et al. (2008a); Suurs and Hekkert (2009); Hermans et al. (2019)

Function	Description
F1: Entrepreneurial activities	New and extant actors' actions to utilize the business opportunities presented by resources, knowledge, networks, and markets.
F2: Knowledge development	Applied and fundamental research on new technological options and production processes.
F3: Knowledge diffusion	TIS actors partner either among each other or with external actors to pursue joint R&D projects and to exchange technological knowledge.
F4: Guidance of search	The process of orientation and selection among different directions of technological development.
F5: Market formation	Introduction of the new technology/product to the niche or mass market.
F6: Resource mobilization	Inflows of financial, human, or natural resources serve to maintain and develop the TIS.
F7: Creation of legitimacy	TIS actors lobby for the development of the new technology and increase its legitimacy before the government, media, and users.

TIS functions can influence and reinforce each other. For instance, public financial support (F6) can facilitate new research projects (F2) aimed at exploring new technological options. The latter might be implemented in a start-up (F1) which, if successful, will bring the new product/process into the market (F5). Practically, there can be numerous short and long "chains" of TIS functions connected by causal logic.

3.3.2. TIS resource portfolio for bioclusters

The TIS functions have often been used among the transition scholars to analyze the dynamics of different resource streams in TIS (Andersson et al., 2018; Rohe, 2020; Nevzorova, 2022; Rohe & Mattes, 2022). Adapting the TIS functional approach, Binz et al. (2016) have conceptualized four TIS resources: knowledge, investments, markets, and legitimacy. TIS actors need these resources to “survive” (Musiolik et al., 2020), and, similarly, the actors in a biocluster, which can be conceptualized as a particular local type of TIS, need these resources to function and promote technological innovations in the bioeconomy. The availability, accessibility, and different configurations of these resources can determine whether or not biocluster actors are successful in their innovation endeavors.

One of the reasons why TIS actors can have unequal access to the four TIS resources is because these resources are distributed unevenly across space (Binz & Truffer, 2017; Rohe, 2020). For instance, biocluster actors might have easy access to local natural resources, but a limited access to TIS-specific resources of investments and knowledge. In this case, biocluster actors should source investments and knowledge beyond the local level, i.e. at regional, national, or even broader geographical levels. TIS actors therefore establish various links and networks with actors situated at different geographical levels in order to access, or “import”, the resources needed for their innovation activities. The spatial embeddedness of TIS resources and the various links enabling their transfer along different geographical levels have been studied within the literature on TISs evolving simultaneously at multiple geographical levels.

Authors have studied different TISs from primarily regional (Rohe, 2020; Rohe & Mattes, 2022), primarily national (Binz et al., 2012; Dewald & Fromhold-Eisebith, 2015), or even primarily global (Binz et al., 2014; Yuan & Li, 2021) perspectives, while augmenting these primary levels with other geographical levels as well, to which they ascribed secondary roles. The connections between and across primary and secondary geographical levels have been considered as well. Studying e.g. vertical (Rohe, 2020) or structural couplings (Bergek et al., 2015; Binz & Truffer, 2017), authors have elaborated on various ontologies of the interrelations, arising primarily from the need to compensate for the lack of TIS resources at one level with resources available at other levels.

In spite of remarkable advances in increasing the spatial sensitivity and resolution of the TIS framework, a lacuna with regard to the local level of TISs remains open. This gap is particularly surprising since the TIS framework has been mostly applied in analyses of the development and diffusion of sustainable technologies (Markard et al., 2012), according to its place as one of the founding frameworks in the field of sustainability transitions (Köhler et al., 2019). The latter, however, stresses that innovations in sustainable technologies often emerge from particular sub-regional localities and networks (Coenen et al., 2012), as well as calls for more attention to local institutions, local resource endowment, local market formation, and local policies (Hansen & Coenen, 2015). In effect, despite the calls to make the TIS framework more representative of local contexts (Coenen et al., 2012; Hansen & Coenen, 2015) and the conceptual leeway to define TISs locally (Carlsson & Stankiewicz, 1991; Markard et al., 2015), the local level has received little to no attention in the TIS literature.

Bioclusters prove to be particularly relevant to address this research gap because, on the one hand, they are local in nature[1] and, on the other hand, they are in a constant interplay with the outside worlds in terms of resource flows. Conceptualizing a local biocluster as the primary level of the TIS and including all the broader level as secondary will offer a truly multiscalar approach toward the technological development in bioclusters. Within such an approach, the configuration and interrelation of TIS resources, such as knowledge, investments, markets, and legitimacy, can be analyzed across all the geographical levels, i.e. local, regional, national, transnational[2], and global.

3.4. Multiscalar approach toward the technological development of bioclusters

The idea of multiscalarity in the technological development of bioclusters becomes evident if we view the development of a biocluster through the lens of the four TIS resource scales, each of which can involve different geographical levels, where the respective resource is embedded. A geographical scale is a broad concept which can be used to measure the spatial extent of various processes (Raven et al., 2012; Schut et al., 2013; Hermans et al., 2016). Having four processes of resource formation, it would be reasonable not to measure them all on one geographical scale, but instead to use four geographical scales, with each measuring one resource flow along the different geographical levels. Fig. 4 presents four geographical scales for studying the multiscalar resource constellations in bioclusters.

The local levels of these four scales are marked as primary because the biocluster operating the biorefinery technology is local, i.e. “smaller” than regional. The interrelations between the local and broader levels can be studied through spatial coupling, indicating how the local level couples with broader levels to source the respective TIS resource.

Incorporating these four scales with all the geographical levels, i.e. from local to global, will generate novel insights on the geography of resource constellations in bioclusters. From a theoretical standpoint, such a study will augment the literature with a new geographical perspective on TISs in which the local level is treated as primary (Coenen et al., 2012), as well as respond to the calls for a bottom-up perspective on TIS building (Wieczorek et al., 2015; Andersson et al., 2018).

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[1] Clusters operating across several regions or countries are rare and are often represented by several local clusters united by a common idea and a formal network (e.g. IAR-Pole, ARRRA).

[2] The transnational level can include a group of countries that can be considered together due to a common administrative, economic, or institutional framework or a geographical neighborhood. For example, the countries in the European Union, BRICS countries, or Sahel countries can be considered as the transnational level depending on the scope of the analysis.

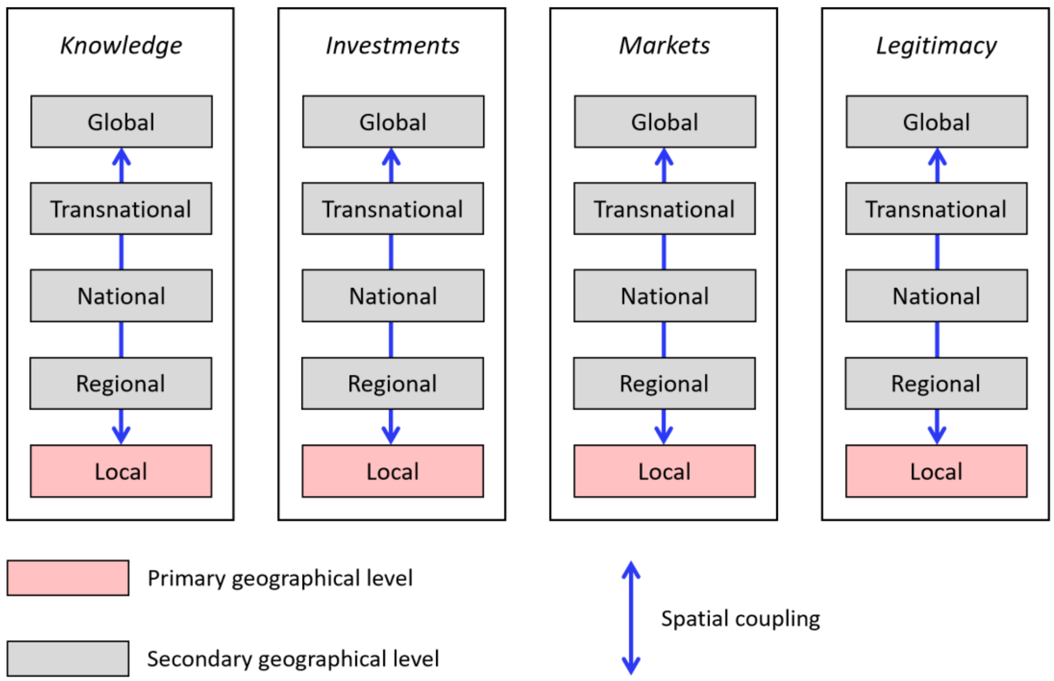

Figure 4. Multiscalar resource constellations for studying technological innovation dynamics in bioclusters

4. Research approach and questions

Both the ecological and technological developments of bioclusters have multiscalar properties at base. The rationale for this multiscalarity stems mainly from the fact that bioclusters are local phenomena. Being, in a sense, a concentration of processes – related both to technological innovations and bioeconomy transition – bioclusters are still in a constant interplay with the world that surrounds them. This interplay can take different forms, depending on whether the ecological or technological development of bioclusters is concerned. While the geographical scale is central in understanding this interplay, expanding our perception of scale and interpreting it along different meanings can shape a more nuanced understanding of how local bioclusters contribute to the global system of bioeconomy transition along the ecological and technological domains. These insights warrant an investigation into the multiscalar nature of the ecological and technological development in the bioeconomy, which allows me to formulate the overarching research question for this dissertation:

How do different scales and their interactions relate to the ecological and technological development in the bioeconomy?

In Chapter 3, I have pointed to specific theoretical gaps and research avenues. At this point, I recapitulate them and formulate three specific research questions.

First, the bioeconomy in general and bioclusters in particular incorporate the issue of sustainability to a large extent. While sustainability issues are acknowledged to have multiscalar and multilevel properties (Cash et al., 2006), bioclusters have not yet been studied from the perspective of the different scales and levels that they incorporate. Bioclusters involve different geographical, institutional, structural, and sustainability aspects, each of which can be represented and measured along different scales. In order to ensure a better management of sustainability issues, all these aspects and the corresponding scales need to be studied simultaneously and a respective framework is needed.

Second, despite using renewable biological resources, bioclusters are not inherently sustainable. While some bioclusters generate positive sustainability outcomes, others can affect sustainability not at all or even negatively (Maya-Ambia, 2011; Hermans, 2018; Asada et al., 2020). There is currently a lack of understanding about how bioclusters contribute to sustainability. Adopting the ideas of scales and scale dynamics from the field of socio-ecological systems, we can understand the sustainability outcomes of a particular biocluster (in my case: the Bazancourt-Pomacle cluster in France). By studying how the scale dynamics evolved along various geographical, institutional, and structural scales, we can capture the effect of these dynamics on specific sustainability scales (Ostrom, 2009; Olsson et al., 2014).

Finally, technological development and innovations in bioclusters depend on the ability of actors to attract and utilize key TIS resources, such as knowledge, investments, markets, and legitimacy (Binz et al., 2016). These resource streams have been often studied by adapting the TIS functions approach. While the literature on multiscalar TISs has analyzed functional interactions across regional, national, and global levels to understand the spatial embeddedness of these four TIS resources, there have been no respective studies in relation to the local level. Local bioclusters operating under a biorefinery model make it possible to conceptualize the BioRefining TIS (BRTIS) from the perspective of the local level, i.e. local BRTIS. The dynamics of the resource streams can then be analyzed from a truly multiscalar perspective by studying the spatial embeddedness of TIS functions and their interrelations across various geographical levels.

I address the above-summarized three research gaps and corresponding avenues by formulating three research questions (RQ):

RQ 1. What are the different scales relevant to study the sustainability effects of bioclusters?

RQ 2. How did scale dynamics lead to sustainability effects during the development of the Bazancourt-Pomacle cluster?

RQ 3. How did the local BRTIS evolve through functional interactions with different geographical levels?

In the next chapter, I present the quantitative and qualitative methodologies used to answer these research questions.

5. Research context and methods

To address the research questions, I applied different methodologies and different research designs. This is due to the fact that my dissertation did not rely thoroughly on pre-existing theoretical frameworks.

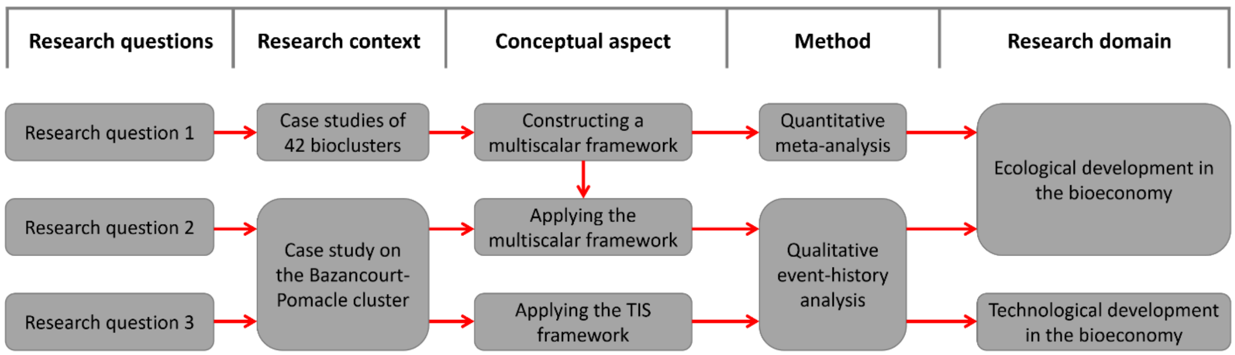

Figure 5. The relations of the research questions to the applied methods, theoretical frameworks, research contexts, and research domains

An existing framework, i.e. TIS, has only been used to study the technological development in the bioeconomy, according to RQ 3. Yet, the studies of the ecological development in the bioeconomy, according to RQs 1 & 2, were not based on pre-existing frameworks, but instead required to build such a framework. Fig. 5 presents the methodological structure of my dissertation. In what follows, I describe the methodologies and research contexts that have been used to answer the research questions.

5.1. Research question 1: Quantitative meta-analysis

The purpose of the RQ 1 was to construct a multiscalar framework that can be applied to study the sustainability effects of bioclusters. For this purpose, we applied the method of quantitative meta-analysis.

The development and the first application of this method is credited to Glass (1976). The method was described as an “analysis of analyses” (p. 3). In other words, it essentially implied analyzing and systematizing the results of different studies that had a common purpose. The final result of a meta-analysis is therefore an overarching, yet more precise answer to the question that minimizes the limitations and biases of individual case studies from the selected population (Rosenthal & Wolf, 1987). Originally applied in the field of biomedical sciences, the method of quantitative meta-analysis over time found its application in the social sciences as well and began to serve the purpose of systematizing not only results, but also insights and perspectives of various independent studies (Matarazzo & Nijkamp, 1997; Ragin, 2014).

Figure 6. Localization of the 42 biocluster case studies
Source: Ayrapetyan and Hermans (2020)

Quantitative meta-analysis serves our purpose because a multiscalar framework for bioclusters is supposed to incorporate a wide range of scales. To derive as many scales as possible, it is necessary to analyze *a large number* of bioclusters from the perspective of scales that are relevant for them. Scholars have previously analyzed one or more bioclusters in scientific articles with a single or multiple case study design. We therefore investigated 35 biocluster case studies indexed in the Scopus database (https://www.scopus.com). Together these articles reported on 42 bioclusters located in different parts of the world (Fig. 6). These biocluster case studies were analyzed from the perspective of scales and levels that were repeatedly mentioned in or identified as relevant for them. More details regarding the application of this method, as well as the results of the analysis are reported in Ayrapetyan and Hermans (2020), attached to this dissertation.

5.2. Research questions 2 & 3

I now present the methodologies and research contexts used to answer research questions 2 & 3. As presented in Fig. 5, RQ 2 relates to the ecological development in the bioeconomy, while RQ 3 addresses the technological development. Even though these research questions relate to different research domains, they employ the same method and case study, which is why I present them together in this section.

5.2.1. Research context: Bazancourt-Pomacle cluster

To study the ecological and technological development in the bioeconomy, according to RQs 2 & 3, we chose an in-depth single case study design (Piore, 2006; Yin, 2018). In contrast to the multiple case study, this approach can bring in more precise conceptual inputs through a deeper understanding and analysis of the selected case (Gerring, 2016; Gustafsson, 2017). The case we selected was the Bazancourt-Pomacle cluster (BPC) located in the Marne department of the Grand Est region in France. We chose this biocluster because it is a perfect case of bioeconomy development from both ecological and technological perspectives.

From the perspective of the ecological development, first, the BPC is currently regarded as the most prominent example of circular bioeconomy in France (Diakosavvas & Frezal, 2019; Philp & Winickoff, 2019). Second, the BPC is a territorial cluster, meaning that it utilizes natural resources from the surrounding region and does not import them from distant regions or other countries (Philp & Winickoff, 2019). Third, besides shaping the local and regional bioeconomy strategy, the BPC also extends its scope of influence over higher geographical levels in the form of knowledge transfer at the national level (Diakosavvas & Frezal, 2019), policy transfer at the EU level, and shaping the bioeconomy markets at the global level (Philp & Winickoff, 2017).

From the perspective of the technological development, first, the BPC promoted innovations based on advanced knowledge developed both within the biocluster, as well as sourced from national and global collaboration networks (Schieb et al., 2015). Second, the BPC attracts significant investments from regional, national, and European funds to further develop its biorefinery technology. Third, the BPC has extended into different markets located at local, national, and global levels. Fourth, over time the BPC has acquired considerable legitimacy among the policy actors, NGOs, and media from all over the world (Philp & Winickoff, 2017). As a result, the BPC hosts one of the largest and technologically-sophisticated biorefineries in the world (Diakosavvas & Frezal, 2019) that actively engages in the flows of TIS resources, such as knowledge, investments, markets, and legitimacy, situated at various geographical levels.

The BPC originated from a single sugar factory set up in 1953 between the communities of Bazancourt and Pomacle (Fig. 7) (Schieb et al., 2015). Agricultural cooperatives in the Champagne region have been playing a crucial role in the formation and development of this cluster (Thénot et al., 2018). The spirit of cooperatives was part of a shared desire to improve both the productivity of farms in the region and to enhance the farmers' living standard (Thénot, 2011). Thus, the grouping into cooperatives was initially thought of as a means of supplying the agricultural equipment and inputs necessary for cultivation. The cooperatives, therefore, played a role in transferring technology from outside to the region. The second problem faced by the farmers was the absence of industrial production tools of sufficient size to carry out the first biomass transformation operations and thus maintain the added value on the territory. Therefore, the cooperative, as an organizational form, was the standard way for the farmers to organize and move toward a common goal of developing localized industrial plants to maintain the value on the territory. Currently, two large-scale agricultural cooperatives are actively involved in the activities of the BPC: Cristal Union – the cooperative of sugar beet growers, and Vivescia – the cooperative of wheat growers (Schieb et al., 2015). Both cooperatives were formed from early mergers of other smaller cooperatives.

Figure 7. The Bazancourt-Pomacle cluster
Source: Google Earth

During a period of almost 70 years (1953-2022), the BPC has developed into what is now considered as one of the most successful biocluster initiatives in France and in Europe (Philp & Winickoff, 2017, 2019). Through efficient resource sharing and application of advanced knowledge, the few inputs of the BPC are transformed into various chemicals, food ingredients, health products, and biofuels, making it one of the most integrated biorefineries.

Currently the BPC is a highly-industrialized area of about 260 ha operating 11 firms and employing more than 2.000 people. The infrastructure of the biorefinery consists of buildings, technological facilities, research centers, production plants and silos hosted by different actors. The annual inputs of the biorefinery are 3 million tonnes of sugar beet, 1 million tonnes of wheat, and 100.000 tonnes of alfalfa. The biorefinery makes a strong emphasis on the use of the whole plant by operating a system of by-product and waste exchange between its actors, hence fully devoting itself to the idea of circular bioeconomy (Thénot et al., 2018; Morales, 2020).

5.2.2. Event-history analysis

The overarching motive behind the research questions 2 & 3 is to find out *how* the ecological and technological *development* in the bioeconomy took place from the perspective of a particular biocluster. To answer *how* a certain *development* took place, we need to look at the events, incidents, and processes, as well as their sequences, cause-effect links, and ensuing results from the perspective of the narrative that we are interested in. The method of event-history analysis (EHA) is designed to serve this exact purpose (Poole et al., 2000; Van de Ven & Poole, 2005).

Originated from the fields of engineering and biomedical sciences (Kiefer, 1988), this method has found a broad application in the social sciences as well. In this field, EHA has been popularized through studies on organizational change and innovation journeys (Abbott, 1995; Poole & Van de Ven, 2004). Within the sustainability transitions literature, this method has been used to study the formation of more sustainable production and consumption practices in the economy from technological and institutional perspectives. Some examples of studies employing this method are the study of Hermans et al. (2016) on the development of coalitions for grassroots innovations in sustainable agriculture, the studies of Suurs and Hekkert (2009) and Hermans et al. (2019) on the realization of innovation system functions in the Dutch technological and agricultural innovation systems, and the studies of Spekkink (2013) and Tziva et al. (2021) on the institutional formation of alliances in the development of bio-based industries.

There are two approaches through which the event-history analysis can be applied: the variance approach and the process approach (Poole & Van de Ven, 2004). Generally, the variance approach interprets outcomes as a result of the presence of a number of factors, without paying specific attention to the sequence and causal logic of the factors themselves. In contrast, the process approach focuses specifically on the temporal sequences of factors – i.e. events – to derive explanations regarding *how* a given outcome was reached as a result of those sequences.

To study how the development of a biocluster took place from the ecological and technological perspectives, we therefore use EHA within the process approach. According to Van de Ven and Poole (2005), scientific explanations within a process approach “tell a narrative or story about how a sequence of events unfolds to produce a given outcome” (p. 1381). This approach assigns particular importance to the construction of the temporal sequence of events arranged in the order of their occurrence over time. The events represent “[…] what central subjects do or what happens to them” (Poole et al., 2000, p. 40), and the subjects – in our case, the different cluster actors and projects – are represented by the entities that initiate or are influenced by the events. The longitudinal event history is then typically interpreted according to a specific narrative (Pentland, 1999), describing the story from the narrator’s perspective.

EHA corresponds to the study of the ecological development of a biocluster, i.e. RQ 2, because, first, events can relate to any of the scales dealing with geographical, institutional, structural, or sustainability aspects of bioclusters. Second, the causal logic among events can reveal the interactions among scales, including those scales that are directly linked to various sustainability outcomes in bioclusters.

In relation to the technological development of a biocluster, the use of EHA is justified because, first, the fulfillment of each of the seven TIS functions can be represented by an event, which is why EHA can serve as a systematic method in this case (Suurs & Hekkert, 2009). Second, events can happen at different geographical levels (Bunnell & Coe, 2001): from local to global, while still being related in a cause-effect logic. Therefore, the causal dynamics of TIS functions, that have been linked to events, will create couplings among different geographical levels as well, making it possible to study how the local BRTIS interrelates with other broader levels through resource flows, represented by the TIS functions. More details regarding the application of this method, as well as the results of the analyses of the ecological and technological development at the BPC are reported in Ayrapetyan et al. (2022) and Ayrapetyan et al. (2023 (forthcoming)) attached to this dissertation.

The data for the construction of the narrative was collected from secondary data sources (including academic literature and news websites), participatory observations, meetings with industry stakeholders, and personal interviews. These data sources and how they were used in the narrative construction are summarized in Ayrapetyan et al. (2022) and Ayrapetyan et al. (2023 (forthcoming)) attached to this dissertation.

5.3. Methodological limitations

The applied methodologies had certain limitations upon which I would like to reflect at this point.

The quantitative meta-analysis used to construct a multiscalar framework for bioclusters was applied in a way different from its conventional application in the literature. Most commonly, this method is used to accumulate and compare the *results* of different studies. In our case, however, it was used to collect information on scales which was not the purpose of the individual case studies in the population of articles. This yields a certain arbitrariness regarding how and if the authors of the individual case studies referred to different scales and levels. This was especially the case with regard to sustainability scales. The literature used for the meta-analysis was rather unbalanced with respect to the roles of economic, social, and environmental effects of bioclusters, with most of the case studies referring explicitly to scales of economic performance while giving few references to social and environmental scales. Consequently, the application of this framework to specific bioclusters would still require to adjust it by eliminating or adding scales and levels.

Regarding the research context of RQ 2 & 3, the single case study approach yields limitations as well. The BPC is a biocluster with primarily local and regional supply of natural resources. This poses a limitation to our understanding of regional sustainability transitions because bioclusters with broader geography of supply chains can pursue different pathways to sustainability and a bioeconomy transition. This limitation holds also in relation to studying the technological development in the bioeconomy through the example of the BPC. Trajectories of technological innovations might differ depending on resource endowment, institutional background, policy frameworks and trust among local actors (Asheim & Gertler, 2006; Binz et al., 2020). Applying our research design to bioclusters different in their geography of supply chains as well as in other institutional, political, and social characteristics would therefore be a welcome addition to the literature.

Finally, even though we used quite different and extensive data sources, there were some aspects that these data could not fully cover. In particular, the data about sustainability effects of the BPC was difficult to obtain. As revealed from the data collection process, information about the complete extent of material flows and product exchanges among actors is often confidential or blocked by actors. An interesting avenue for future research is therefore to inquire into the reasons as to why the access to such data is obstructed.

6. Research papers

After presenting the methodologies and research contexts, I now describe the individual research papers that form this cumulative dissertation. The full research papers are listed at the end of this dissertation. Before providing the summaries of the three research papers in the next three sections, I present the overview of these papers in Table 3.

Table 3. Overview of the research papers

Title	Highlights	Authors	Journal (IF)
Introducing a Multiscalar Framework for Biocluster Research: A Meta-analysis	- A meta-analysis of 42 biocluster case studies - Multiscalar framework to study sustainability effects of bioclusters - The relationship of economic, social, and environmental performance tested for bioclusters - Literature focuses mainly on economic performance of bioclusters	David Ayrapetyan (80%), Frans Hermans (20%)	Published in Sustainability (3.889)
The role of sustainability in the emergence and evolution of bioeconomy clusters: An application of a multiscalar framework	- Longitudinal scale analysis of sustainable development of Bazancourt-Pomacle cluster - Sustainability improvements in bioclusters are natural results of actors' activities - Knowledge synergies in clusters relate to product synergies in bioclusters - Scale perspective facilitates observability and measurement of sustainability effects - Potential of scale perspective for studying bioeconomy trade-offs is explored	David Ayrapetyan (80%), Frans Hermans (10%), Nicolas Befort (10%)	Published in Journal of Cleaner Production (11.072)

From local markets to global legitimacy: A bottom-up perspective on technological innovation system's dynamic	- A new, local, spatial perspective on TIS dynamics - A case study on global biorefining TIS from a local perspective - The geography of key TIS resources is explored for a biocluster - Strengthening legitimacy boosts local actors' access to TIS resources - Policy should shape local biorefinery markets and disseminate their legitimacy at the global level	David Ayrapetyan (90%), Frans Hermans (5%), Nicolas Befort (5%)	Under review in Research Policy (9.473)

6.1. Introducing a Multiscalar Framework for Biocluster Research: A Meta-analysis

The first paper (Ayrapetyan & Hermans, 2020) is premised on the observation that bioclusters, despite incorporating the issue of sustainability at multiple scales and levels, have not yet benefitted from a multiscalar approach and a respective framework to systematize the scales and levels for bioclusters has been missing. Aiming to construct such a framework, the paper combines insights about scales from the literature on sustainability transitions, socio-ecological systems, and cluster life cycles and complements the scales found in these streams of literature with scales relevant specifically for bioclusters.

To identify the biocluster-specific scales, the paper draws on a meta-analysis of 42 case studies on bioclusters, found by running a specific search query in the Scopus database. The content of these case studies is analyzed to find repetitive references to scales and levels, which are then extracted and added to the multiscalar framework.

The paper answers the RQ 1 in that it constructs a multiscalar framework relevant to study sustainability effects of bioclusters. The multiscalar framework includes scales measuring their resource supply chains, financial and knowledge flows, administrative and institutional embeddedness, as well as cluster size and various cluster network characteristics. We group all these scales into two dimensions: (1) cluster attributes and (2) cluster links to the outside world. The multiscalar framework allocates a separate space for different sustainability scales that are integrated into economic, social, and environmental performance of bioclusters. The study also reveals that bioclusters with better economic performance tend to score higher on the social and environmental scales as well. The paper ends with a discussion on the correlation and overlaps by applying the Pearson correlation coefficient measure to the 14 scales that comprise the multiscalar framework.

6.2. The role of sustainability in the emergence and evolution of bioeconomy clusters: An application of a multiscalar framework

The second paper (Ayrapetyan et al., 2022) aims at increasing our understanding of the processes through which bioeconomy clusters generate sustainability effects and promote the bioeconomy transition. From the conceptual perspective, the paper draws deeper insights into the similarities and differences of the concept of scale in sustainability transitions and socio-ecological systems literature. It argues that while the field of sustainability transitions interprets "scale" and "multiscalarity" only in relation to the geographical scale, the socio-ecological systems literature uses these terms to highlight the existence of not only geographical, but also other scales, such as administrative, institutional, structural, and sustainability scales. Given that the sustainability of bioclusters should be studied in the context of its interrelations with various administrative, institutional, and structural aspects, it is proposed that the interrelations and dynamics along these scales can reveal how bioclusters become more or less sustainable over time. While the first paper (Ayrapetyan & Hermans, 2020) identified *which* scales should be considered while studying bioclusters, the conceptual contribution of the second paper lies in identifying *how* these scales are related and *how* they relate to the process of improving the sustainability of bioclusters.

Empirically, the paper focuses a single case study biocluster – the Bazancourt-Pomacle cluster in France – which is emblematic of a knowledge-based, sustainability-oriented biocluster with a strong influence in Europe and worldwide as a successful biocluster model. We analyze the event-history of this biocluster and interpret its development as a continuous interplay among its geographical, institutional, and structural scales to capture how these dynamics eventually affect specific sustainability scales. We adapt the multiscalar framework developed in the first paper, which thus serves as a tool to conduct the multiscalar analysis.

The paper answers the RQ 2 in that it reveals how scale dynamics led to sustainability effects during the development of the BPC. The identified scale dynamics revealed a specific sequence of cross-scale interactions repeating in different stages of the BPC development. This pattern suggests that the biocluster actors adopted a specific mode of action by organizing their activities along scales related to the valorization of local natural resources and that sustainability followed as a posteriori result of these activities rather than being an aim in itself. We also found that the actors could maintain their mode of action in different stages of the BPC development due to changes along other scales, not related to sustainability directly, such as institutional, political, and social scales. The issue of sustainability is, therefore, better viewed as a part of regional diversification path, rather than a goal in itself.

6.3. From local markets to global legitimacy: A bottom-up perspective on technological innovation system's dynamic

The third paper (Ayrapetyan et al., 2023 (forthcoming)) applies a TIS perspective to technological development in the bioeconomy. It reviews different TIS studies that analyzed the dynamics of TIS functions and the associated TIS resources from the perspective of their interactions along regional, national, and global geographical levels. The paper argues that the local level has not yet been the primary geographical focus in the TIS literature and that the interplay of TIS resources along local and broader levels has therefore not been investigated. The paper addresses this gap by conceptualizing a new spatial perspective on TISs in which the primary focus is directed to the local level that interacts with broader levels through spatial couplings.

Empirically, the paper focuses on a particular local level of the global BioRefining TIS (BRTIS). The local BRTIS is represented by the BPC that hosts one of the largest and technologically-sophisticated biorefineries in the world that actively engages in the flows of TIS resources, such as knowledge, investments, markets, and legitimacy. Using event-history analysis, we explore how the local BRTIS, evolved through interactions of TIS functions and associated TIS resources embedded in local, regional, national, European, and global levels.

The paper answers the RQ 3 in that it reveals how the local BRTIS evolved through functional interactions with different geographical levels. These results are presented by summarizing the functional dynamics of the local BRTIS within the local level, as well as by summarizing the functional interactions, i.e. spatial couplings, of the local BRTIS with regional, national, European, and global levels. These dynamics are described by shifting configurations of TIS functions at various levels in different periods. While the key role of the regional level was described by providing guidance and investments, broader spatial levels took over more diverse and flexible roles by forming markets for and disseminating the legitimacy of the local BRTIS. The evolution of the local BRTIS from the TIS resource perspective is illustrated by the results on the constellations of TIS resources measured at four geographical scales: knowledge sources, investment sources, markets, and legitimacy. In particular, the geographical distribution of market formation processes, described both by local markets of by-products and markets of bio-based end products at broader levels, increased our understanding of spatiality and types of markets in TISs. Furthermore, the spatial characteristics of legitimation processes of the local BRTIS revealed the importance of technology legitimation at broader levels and its potential to expand the access to resource for the local actors. Stimulating biorefinery-internal local markets and disseminating local success stories at broader levels are identified as important targets for biorefinery policy.

7. Conclusion and implications of results

This doctoral dissertation explored the sustainability transitions and technological innovations in the bioeconomy through a multiscalar lens, by explicitly focusing on the question how different scales and their interactions drive ecological and technological developments in bioclusters.

Regarding the ecological development in the bioeconomy, the multiscalar dynamics among scales related to the valorization of renewable natural resources can lead to various outcomes on specific sustainability scales which, in turn, are often linked by trade-offs. Positive sustainability outcomes can be achieved if these multiscalar dynamics are maintained over time through the necessary configurations on other scales, such as the administrative, institutional, and structural scales. Regarding the technological development in the bioeconomy, the multiscalar constellations and dynamics of TIS-resource scales can shape favorable conditions for local actors to appropriate local markets, spread the legitimacy of biorefining technologies at broader levels, as well as source knowledge and investments from local, regional, and national levels.

In this final chapter, I reflect upon the implications of the results reported in the three research papers. In Section 7.1, I discuss the theoretical relevance of the results and how they fit into the literature on geography of Sustainability Transitions and Technological Innovation Systems. In Section 7.2, I illustrate the practical relevance of the results for policy makers, managers, and practitioners who aim to further the ecological and technological development through bioclusters.

7.1. Theoretical implications

This dissertation revealed the multiscalar nature of sustainability transitions and technological innovation systems on the example of a local biocluster. The three research papers comprising this dissertation addressed the following theoretical gaps and open questions identified in the literature on sustainability transitions, technological innovation systems, and their geographies: What scales and levels should be considered when studying or managing bioclusters that can address the issue of environmental sustainability? How do different geographical, institutional, and structural scales relate to each other in the process of bioclusters becoming more sustainable? In what ways is biocluster development similar to or different from the known trajectories of diversification of regions to sustainability? How can the dynamics of technological innovations be analyzed from a primarily local perspective? What is the role and dynamics of multiscalar TIS resources in the process of the local, bottom-up innovation system building?

We designed our multiscalar framework with the purpose to study bioclusters from the viewpoint of the cause-effect links that the different sustainability effects can have across different scales and levels. The multiscalar framework is a combination of scales and levels derived both from the existing theoretical literature and from a number of biocluster case studies. Therefore, the multiscalar framework is a response to different authors calling for more attention to the process of inclusion and exclusion of different scales (Vervoort et al., 2012; Schut et al., 2013; Hermans et al., 2016).

The new multiscalar framework proved useful to study bioclusters that constitute a specific form of infrastructure for the regional sustainability transition to the bioeconomy. The primary focus on the local level – a biocluster – allowed us to explore the complex dynamics among different scales, not necessarily conforming to the strictly geographical perception of scale found in the geography of sustainability transitions. The study on the ecological development of the BPC implied a common interaction pattern among the different scales of this framework. These multiscalar interactions unfolded along scales directly related to the valorization of renewable natural resources, and, therefore, constitute the mode of action of the biocluster actors. However, keeping this mode functioning was possible due to the institutional, political, and social adjustments on the respective scales, not directly related to sustainability. It comes from this result that the driving force in the development of bioclusters is not the issue of sustainability. Instead, the latter appears as a posteriori result that help the actors to generate their own (local) vision of sustainable development used to legitimize practices and attract public support.

These findings therefore contribute to the literature on sustainability transitions by revealing how the various institutional, political, and social factors, that have been acknowledged to influence the spatially uneven transition processes (Köhler et al., 2019; Miörner & Binz, 2021), can relate to and create the environment for the sustainability transition in the context of local bioclusters. By analyzing sustainability scales and their dynamics in relation to other types of scales, our study also responds to authors calling for the inclusion of sustainability scales in analyses of systems working toward sustainability transitions (Hermans et al., 2016; Olsson et al., 2014).

Current debates on the geography of sustainability transitions focus on the role of pre-existing knowledge bases and capability portfolios in fostering the development of diversified regional paths (Binz et al., 2020). In line with the work on evolutionary economic geography, the key role of extant knowledge bases has been demonstrated in the diversification of regional trajectories. From this viewpoint, the BPC is an original case of exaptation. Indeed, exaptation corresponds to a diversification logic driven by existing knowledge and technologies (Boschma et al., 2017). In the case of the BPC, the development trajectory relies on local natural resources (sugar beet and wheat), which allows us to formulate a different, i.e. natural-resource-based, exaptation trajectory pertinent to bioclusters. In the natural-resource-based exaptation trajectory, incumbents play a key role because they control the access to natural resources. These incumbents have strong political support that enables them to attract funding to support their projects. However, this support is mainly local and regional. In doing so, they are able to diversify within a very closed network. Entrepreneurship here is controlled by these same incumbents, which explains the strong technological lock-in around the possible uses of local natural resources possibly leading to extractivist practices in the agro-industrial sector. Therefore, in light of the debates on the bioeconomy (Befort, 2020; Hellsmark & Hansen, 2020), the sustainability of regional paths followed by bioclusters should not be taken for granted. Our insights contribute to the geography of sustainability transitions by integrating the issue of sustainability not as a given but as a part of the diversification process of regional pathways.

The study on the technological development in the bioeconomy offered a new spatial perspective for TIS analysis. The results contribute to the debates in the TIS literature (Coenen et al., 2012; Binz & Truffer, 2017) by conceptualizing a new TIS perspective in which the primary focus is devoted to the local level that is linked to all broader levels through spatial couplings. Incorporating the whole range of geographical levels, i.e. from local to global, in a single case study, responds to the respective call made by Andersson et al. (2018) for a truly spatial approach in TIS. We also attended to the research avenues pointed to by Wieczorek et al. (2015) and Miörner and Binz (2021) in that we studied the local TIS formation from the a bottom-up perspective by exploring how actors themselves defined the system following the resources, networks, and value chains at different spatial levels in different periods.

Finally, the study contributes to the debate on TIS resource constellations that local actors need to "survive" (Binz et al., 2016; Binz & Truffer, 2017; Musiolik et al., 2020; Rohe, 2020). The new local TIS perspective allowed us to study the spatial embeddedness and dynamics of four key TIS resources, i.e. knowledge, investments, markets, and legitimacy, from a truly multiscalar perspective. These resources and their dynamics were studied along four geographical scales, each incorporating all the levels of the scalar distribution, i.e. from local to global. In the case of local innovation system building, we observe different constellations of TIS resources on the respective scales in different periods. The local actors accessed new knowledge at local, regional, and national levels, while anchoring it more to the local level over time. We observe the same geographical distribution on the scale of investment mobilization, although without anchoring to any particular level over time. The geography of niche market formation indicates the formation of markets at local, national, and global levels. Interestingly, we discovered the existence of two types of markets that biorefineries can form: markets for by-products and markets for end products. Moreover, the former took place only locally, whereas the latter were formed predominantly at the national and global levels. These results contribute to the literature on spatial characteristics of market formation in TISs (Dewald & Truffer, 2011, 2012; Boon et al., 2020) by distinguishing between local and extra-local geographies of market formation in biorefineries. The local actors "exported" the creation of legitimacy to national, European, and global levels, while focusing more on global legitimation over time. Once the legitimacy of the local BRTIS reached the global level, the local actors could expand their access to resources to regional and national levels as well. This is illustrated by the increasing effect of these levels on local entrepreneurial activities in the period of diversification, when the legitimacy of the local BRTIS reached the global level. These results therefore add to the literature on legitimacy of TISs (Markard et al., 2016) and to the emerging debates on spatial aspects of legitimacy (Andersson et al., 2018; Heiberg et al., 2020; Rohe & Chlebna, 2021). In particular, they resonate with findings of Andersson et al. (2018) regarding the non-sticky nature of legitimacy, and also respond to the recent call by Rohe and Chlebna (2021) for deeper insights on spatial and temporal dynamics of legitimation and its relation to other TIS functions.

7.2. Practical implications

In addition to the theoretical contributions, this dissertation also had implications for practitioners, managers, and policy makers interested in promoting the ecological and technological development in the bioeconomy. In this final section, I summarize these implications that are described in more detail in the research papers.

Currently, one of the central challenges of the bioeconomy is to increase the scale of production, while simultaneously balancing it with the sustainability aspect (Pfau et al., 2014). While bioclusters can drive the bioeconomy development through the creation of synergies in the use of renewable natural resources, this development often encounters trade-offs as well (see Section 5.2 of Ayrapetyan et al. (2022) attached to this dissertation). The example of the BPC revealed that achieving additional sustainability benefits might come at a cost of extended supply chains which in turn can affect sustainability negatively. While the lack of access to the relevant data did not let us measure other trade-offs in this case, such trade-offs are nonetheless common in the bioeconomy and in the management of natural resources in general (Rodríguez et al., 2006; Klasen et al., 2016; Asada et al., 2020). The application of a multiscalar framework will facilitate a better management of trade-offs in bioclusters by showing how advancing along certain sustainability scales comes at a cost of falling back on other sustainability scales. A multiscalar framework, as illustrated by our results, can provide a clear picture regarding such trade-offs that are represented as cross-scale and cross-level interactions on sustainability scales. This way of scalar representation might therefore facilitate better monitorability of sustainability effects, rendering the bioeconomy initiatives more welcome and trustworthy for a broader circle of relevant social and policy actors (Asveld et al., 2015; Ribeiro & Quintanilla, 2015).

Our study yielded important implications for policy makers and managers aiming to improve the sustainability of bioclusters. As revealed in the multiscalar analysis of the second research paper, biocluster actors follow a certain mode of action that can be represented by scales of valorization of local natural resources. Keeping this mode functioning in different cluster development stages required various changes and adjustments reflected on administrative, institutional, and structural scales, i.e. scales not related to sustainability directly. Instead of trying to affect sustainability outcomes in bioclusters, policy should instead shape the relevant administrative, institutional, and structural configurations in bioclusters. Creating and adjusting these configurations according to the needs of local actors in different periods would allow them to keep functioning through practices that in turn lead to sustainability. In more simple terms, policy efforts aiming to improve sustainability of bioclusters are better realized not by addressing sustainability itself, but by creating the conditions for actors to keep functioning in ways that lead to sustainability.

Our study yielded locally-tailored policy recommendations for promoting the biorefining technology in bioclusters. Motivating businesses to join biorefineries and, therefore, promoting their growth has been a complicated issue (Bauer et al., 2017). In this regard, a clear policy target is revealed based on our results on the market formation processes in biorefineries. In trying to stimulate firm entry, the policy should promote the formation of internal markets in biorefineries. The case of the BPC revealed that the primary driving force for firms to join the biorefinery was the opportunity to utilize and benefit from the existing market of by-products at the local level, especially in the later periods of development. Increasing the offer of available local streams of by-products both in terms of their quantity and diversity, might attract outside actors to join biorefineries. Promoting biorefinery-internal market of by-products is likely to address also the issue of supporting biorefinery markets of advanced end products. Given the commonly-supported markets for biofuels and bioenergy, markets for other bio-based materials and products have not been provided a level playing field from policy (OECD, 2017). In our case, local market formation appeared as a pre-requisite for firms to be able to target markets of bio-based end products. Therefore, biorefinery policies should focus more on shaping existing local markets as “protected spaces” (Bergek et al., 2008b) that firms can rely on and use to target markets at broader geographical levels as well.

Finally, policy makers can also use the legitimacy of biorefining technologies as a tool to support local biorefineries. Our results showed that the BPC managed to strengthen its legitimacy in different ways, such as involving multinational corporations and intergovernmental organizations in its activities, spreading local success stories through media and NGOs, and showcasing the potential of local firms to enter global markets. These legitimacy-building events took place predominantly at the national and global levels, and enabled local actors to access more resources for their activities. Policy should therefore aid in spreading narratives (Heiberg et al., 2020) about successful technology trials and ecological advances of local biorefineries, especially among transnational organizations operating at international and global levels. This likely to increase the legitimacy of sustainable technologies and lead to a broader societal acceptance of the consumer products.

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sustainability

Article

Introducing a Multiscalar Framework for Biocluster Research: A Meta-Analysis

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Abstract: Bioclusters have grown in popularity in the last decade in response to the global environmental and climate challenges. These clusters envisage sustainable and local production value chains in different sectors of the bioeconomy. However, the sustainability of these clusters is often questioned because of the negative social and environmental effects they can have both inside and outside of their region. At present, a framework is missing to analyze these effects that span multiple levels and multiple scales. The aim of this paper is to develop such a multiscalar framework. For this aim, we conducted a meta-analysis of biocluster case studies. As a result, we constructed a framework that combines the aspects of sustainability, knowledge and resource flows, cluster network properties, and the political and institutional structures. We tested this framework on the question of how the different scales of biocluster performance interact and depend on each other.

Keywords: bioeconomy; biocluster; sustainability; scales; transition; meta-analysis

1. Introduction

The bioeconomy was originally envisaged as an alternative economic system that would not jeopardize the environment, and that would provide a safe living for future generations [1]. In recent years, this concept has been growing in popularity, in both the science and the policy arenas, as a potential way of organizing production and consumption practices in society in a more sustainable way by using renewable and biological resources instead of fossil fuels [2]. In a bioeconomy, energy, materials, chemicals, food, and feeds are produced using plant and animal sources [3,4]. The hope and expectations of a bioeconomy are that it can combine combatting climate change and the reduced use of fossil fuels with the promotion of innovation, the knowledge economy, and rural and regional sustainable development [5,6]. As such, a transformation toward a bioeconomy promises innovative and sustainable use of renewable biological resources in different sectors of the economy, and opens new avenues to reach different Sustainable Development Goals (SDGs) [7,8].

However, a bioeconomy transformation does not automatically imply sustainability. Carelessly designed bioeconomy strategies can lead to economic, social, and environmental problems [9]. The history of first-generation biofuels reminds us how different issues related to indirect land use, deforestation, biodiversity losses, and negative social and environmental effects might arise at different geographical levels [4,10–13].

Therefore, one of the central challenges of the transformation process toward a bioeconomy is dealing with the inherent complexity of increasing the scale of production, while at the same time balancing the social and environmental aspects of sustainability that contain many of the SDGs [4,14]. In order to deal with this complexity, it is necessary to develop a framework that addresses the question of how certain developments on one level ultimately influence processes occurring at other levels, because in complex systems, cause and effects are often linked at different scales and levels [15,16].

Such a scale-sensitive framework is especially relevant for bioeconomy clusters (hereafter, bioclusters) that are nowadays central to many national bioeconomy policies and will play an important role in bioeconomy transition [8,17,18].

Economic activities tend to cluster in specific regions [19,20], and the activities in the field of bioeconomy are no exception. Clustering may promote innovativeness, productivity, regional economic development, employment, and business competitiveness [21–25]. The transition to the bioeconomy is often practiced in bioclusters in Europe and all over the world [17]. These bioclusters are used by the governments to strengthen the collaboration between different bioeconomy actors and, ultimately, to contribute to active learning and to enhance the innovative activity in the bioeconomy. Building upon the cluster definition of Porter [26], we define bioclusters as specific types of sustainability-oriented clusters that constitute geographically proximate and interconnected firms and organizations specializing in various fields of bioeconomy. Different types of bioclusters vary in their resource use, production, structure, and goals [17]. One common biocluster classification is the "colors" of the Knowledge-Based Bio-Economy (KBBE) concept [27]. The "green" KBBE clusters focus on the agro-food sector with agricultural resources as inputs, the "white" KBBE clusters are more industrialized types of bioclusters focusing on bioenergy, biochemicals, food ingredients, pulp and paper, etc., the "blue" KBBE clusters cultivate and process marine biological resources, and the "red" KBBE clusters largely focus on healthcare, bio-pharmacy, and clinical research.

Bioclusters prove to be particularly relevant for developing a multiscalar framework, because, first, they are supposed to work on sustainability and to maintain sustainable interaction between ecology and economy [28]. Second, bioclusters offer the opportunity to localize the whole production value chain within the same region [29,30], while simultaneously being embedded into the global resource streams. This means that a multiscalar framework for bioclusters would combine scales accounting for the processes both inside and outside of the biocluster. The primary aim of this paper is thus to develop a multiscalar framework that makes it possible to study their sustainability effects at different scales and levels.

This paper proceeds as follows: in Section 2, we discuss the concept of scales and multiscalarity, their importance in sustainability issues, and their application for biocluster analysis. Section 3 describes the methodology of this study. Results of our research are presented in Section 4. Section 5 provides a discussion of the results, and the paper ends with a conclusion.

2. The Concept of Scales and Multiscalarity

We argue that biocluster research requires a more scale-sensitive approach in order to ensure more stable and reliable prospects for the bioeconomy. Studies on human–environment dynamics [31], socio-ecological systems and resilience [32], policy debates on sustainability [33], and the development of agricultural grassroots innovations [34] have previously applied scales, levels, and dimensions. These concepts become central to our research design as a means to better understand the biocluster-internal aspects, and the different connections of bioclusters to the outside world.

2.1. What Are Scales

Scales are widely applicable in modern society due to the way the latter is structured [35,36]. The decisions people make, the laws they pass, the rules they follow, the knowledge they exchange, etc. all happen on different levels that are either formally defined or socially created. The meaning of terms like dimension, scale, and level differs depending on where and how they are applied [37,38]. We define them based on Gibson et al. [36], who refer to *dimensions* as concepts we want to study, *scales* as measures for different spatial, temporal, quantitative, or analytical aspects, and *levels* as specific positions on those scales. A schematic illustration of two scales with different numbers of levels is shown in Figure 1. The lower levels on the scales correspond to the lower magnitude of the scale. Accordingly, the higher levels stand for the higher magnitude.

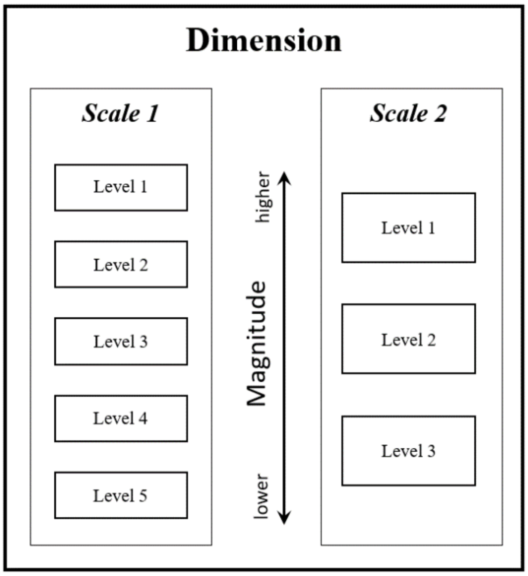

Figure 1. Schematic illustration of the scales and levels (based on Cash et al. [31] and Vervoort et al. [35]).

The levels on the scale present information about the scale. Scales can have nominal, ordinal, interval, and ratio levels. In our framework, we assume a basic order or hierarchy between levels, which means we do not incorporate "unordered" nominal scales (such as male and female gender levels). Ordinal scales have a basic order in their levels that can be qualitatively expressed in higher and lower levels. Interval and ratio scales contain levels that can be quantified. Interval scales have levels with proportionate intervals between levels, and ratio scales also include a true zero point. Temperature can be measured in Celsius or Fahrenheit (interval scales) or in Kelvin (ratio scale).

In Figure 2, we illustrate this with examples of six scales and discuss them in the context of their application in cluster analysis.

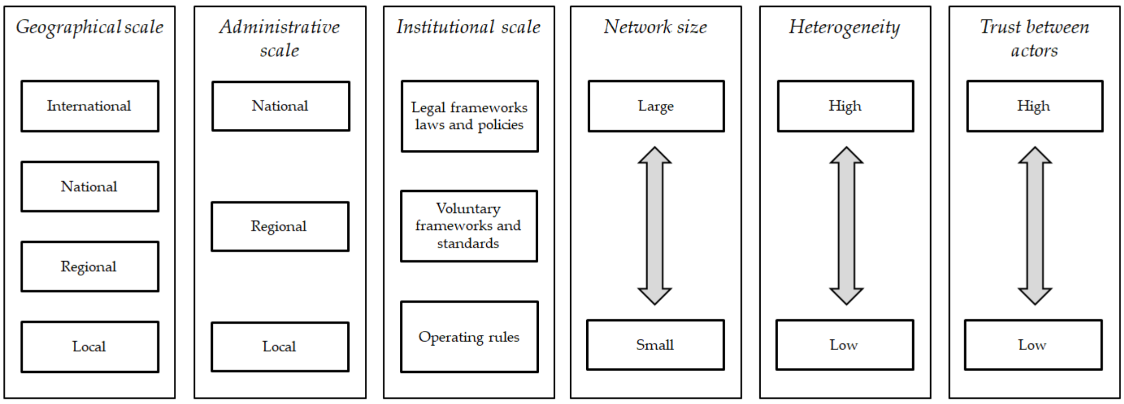

Figure 2. Illustration of geographical, administrative, institutional, network, heterogeneity, and trust scales and their associated levels.

The most commonly used example of a scale in sustainability research is the geographical scale. It is used to measure the spatial range of events and processes [31,33,34,36,37]. The levels on the geographical scale denote the exact specification of the territorial boundaries: these are usually the local, regional, national, international, and sometimes the global levels. For clusters, this scale is relevant to measure their geographical span. Newly emerging clusters are often small and thus local in nature [39], but over time clusters can grow or merge, crossing regional and even national boundaries. The administrative scale includes the various levels of government that influence the cluster through the laws and regulations that apply for the cluster [31,34]. The institutional scale represents the hierarchy of rules, laws, and regulations [31,33,34]. The levels on this scale illustrate how agreements between actors can evolve from some simple informal rules to the formal laws and constitutions. In small emerging clusters, informal rules may suffice to coordinate activities, but as clusters grow in membership, these informal rules often need to become more formalized and codified. These three scales are widely applied in the literature on sustainability, human agency, and social change [31,33,34]. We consider these scales as primary for cluster analysis, because they address the key elements of space, power, and governance.

The geographical, administrative, institutional, and trust scales are ordinal scales: they have qualitative levels with a certain order. The network size is a ratio scale (it has a true zero point). It measures the size of a cluster by the number of actors and can indicate any value from zero up to the largest observed quantity of actors. All these values would be the possible levels on this scale. The heterogeneity scale says something about the composition of the cluster, based on economic sector classifications such as NACE or ISIC. The amount of different economic sectors within the cluster can be measured quantitatively in certain intervals. The heterogeneity scale can thus have all the possible values between homogeneous actors (only producers or manufacturers from the same sector) and complete heterogeneity: all actors from different sectors.

Literature on scales and their application often point to an important issue of completeness of scales as well as issues such as complementarity, substitutability, or independence [33–35]. It is problematic to ensure that, in a given scale analysis, all the relevant scales and levels have actually been included. This issue may not be highly problematic for natural scientists, because they normally share a common understanding of the existing hierarchies and levels within their disciplines [36]. In social sciences, however, there is no common consensus as to which scales and levels constitute the studied phenomenon. This is especially the case for issues related to the essentially contested concept of sustainable development: there is no single definition that covers all its different aspects [40,41]. Consequently, researchers, guided by their interests in a particular discipline, often choose the scales and levels arbitrarily to some extent [33,36].

Since the primary aim of this paper is to create a multiscalar framework for bioclusters that can help to study their effects on multiple scales and levels, this is an important issue to be aware of. For instance, it is possible to notice overlaps within the scales we illustrated in Figure 2. The scale of trust and the institutional scale may overlap because a high level of trust between actors is likely to be a pre-requisite to maintain informal operating rules in a cluster. Alternatively, considering the scales of geography and network size, an emergent cluster with a small network size is unlikely to spread beyond the local geographical level.

Another problem related to the use of scales has to do with their measurement. For instance, a quantitative scale such as network size can be relatively easy to measure if the data on the number of actors in the cluster is available. On the contrary, measuring a qualitative scale such as trust is likely to be a complicated task, because it would require collecting and analyzing sensitive data on personal and cooperative relationships between actors in the cluster. This is not to say that qualitative scales are more difficult to measure than the quantitative scales. Instead, the measurement difficulties depend on the data, on which the scale is built, and on the concept behind the scale. This is especially the case for sustainability issues that we will discuss in the next section.

2.2. Scales for Sustainability Performance of Bioclusters

Scales and scaling are especially important for decisions and processes dealing with sustainability [31]. This is due to the complexity of sustainability issues that are not confined to activities and processes happening on a single scale or a single level. Furthermore, when a sustainability issue is discussed, researched, or managed, it is often the case that a single set of processes is cut from the general context, whereas the related effects occur on the higher levels or on other scales [31]. This also seems to be related to the conformist tendencies of the traditional scientific and managerial approaches toward adhering to their own disciplinary scopes [42]. If these tendencies prevail, it may result in adverse effects and unexpected outcomes that Cash et al. [31] generalize under the idea of scale challenges such as ignorance, mismatch, and plurality.

An ignorance challenge arises when certain scales, levels, or their dependencies are not taken into account. This challenge commonly manifests in the consequences that a managerial effort on a certain level has on other levels of the same scale. The challenge of mismatch may occur when the characteristics of an institution at a higher level do not fit those characteristics at lower levels. Finally, the plurality challenge has its roots in the tendency to devise simple and manageable solutions, designed to satisfy all actors involved in a scale. However, there is often strong heterogeneity in the way actors perceive and value the scale [31]. As mentioned by Loorbach and Rotmans [43]: " . . . a practical implementation of sustainable development has to incorporate the inherent conflicts between the values, ambitions, and goals of a multitude of stakeholders." An inadequate representation of all of the stakeholders and their interests at a certain scale or level can bring about the challenge of plurality [33,38].

For the application of bioclusters, this means we should look for specific sustainability performance indicators. Conventional clusters are known to have advantages regarding economic performance, which include increased innovativeness, productivity, employment, and competitiveness [22–24]. Successful clusters are supposed to have and maintain these advantages. Bioclusters differ from conventional clusters in that they can work toward sustainability [3,8,28,44], and this means that the performance of bioclusters should be broadened to include social and environmental scales as well [3,8,44].

In line with the second aim of our study, we want to test the relationship among the economic, social, and environmental performances of bioclusters. Therefore, we included the three scales of biocluster performance into the multiscalar framework. However, the issue of completeness of scales, discussed in Section 2.1, might become even more complex if we use scales to measure sustainability. Which scales best represent the different sustainability pillars? Although attempts have been made to structure the different SDGs along the three sustainability pillars [45,46], there has been limited consensus so far. This means that we have not classified the scales of economic, social, and environmental performances into a single dimension beforehand, because they can represent a multitude of different indicators and effects. Instead, we will look at the literature through a meta-review and classify some of the indicators we find there in these three broad categories of biocluster sustainability performance. Building on the ideas discussed above, the two aims of this study are as follows: first, to develop a multiscalar framework for bioclusters, and second, to test the relationship among the economic, social, and environmental performances of bioclusters. To reach the aims of our study, we conducted a systematic review of biocluster case studies. The next section presents the methodology of our review.

3. Data and Methodology

For integrating results, insights, or perspectives from different independent studies, scholars often use the method of quantitative meta-analysis [47,48]. Using this method, we analyzed the content of different biocluster case studies to find out the scales and levels involved in these bioclusters.

3.1. Article Retrieval

This study is based on the data derived from 35 articles on biocluster case studies indexed in the Scopus database (https://www.scopus.com). Keyword selection was the main tool for identifying the necessary literature. Following the advice of Ramcilovic-Suominen and Pülzl [4], we did not restrict the notion of a bioeconomy to its novel sense of highly engineered bio-based manufacturing that is at the forefront of the current European Union bioeconomy policy. Instead, we took a broader perspective and considered sectors such as forestry, agriculture, and fisheries. We thus developed an algorithm that searched for the words bioeconomy, biobased, eco-industrial, cleantech, biofuel, agroindustry, agribusiness, wood, mari*, and aqua* occurring together with the words cluster, industrial district, agglomeration, park, innovation ecosystem, and industrial ecosystem in the titles, abstracts, and keywords of the articles. Truncations and hyphens created variations of the terms to account for different endings and writing styles. For better precision, we excluded a number of fields from the Scopus subject areas of health sciences, life sciences, and physical sciences. We adjusted the search query to include only publications in English from the period 2000 to 2018. The final search query was run in July 2018 and produced 4027 articles.

3.2. Inclusion Criteria

In order to filter out the necessary case studies from the 4027 results, we refined them by applying four inclusion criteria. First, we only considered articles with case studies of bioclusters. Even though we chose the search keywords and their combinations in a way to retrieve the case studies of bioclusters, only the vast minority of the 4027 results in fact met our expectations. This was because the keywords in the algorithm were still widely used in all kinds of articles that did not focus on case study bioclusters. Fortunately, a quick look at the title and sometimes the abstract made it clear whether the article was a biocluster case study or not. This was the most important filtration step and allowed for the exclusion of around 95% of the articles. Formally, we considered only clusters working with renewable biological resources, which is in line with the definition of bioeconomy used in this paper [3]. Second, we included articles that studied only bioclusters existing in reality. To clarify, we considered bioclusters that were in fact located in some parts of the world regardless of their status or performance compared to other bioclusters. The articles we excluded at this step were those creating (computer) models of bioclusters or designing hypothetical bioclusters for the specific aims of their studies. Third, we excluded case studies of "red biotechnology" clusters focusing on healthcare, bio-pharmacy, and clinical research [27]. These type of clusters, also commonly referred to as, simply, "biotech" clusters, operate largely independently from biomass streams [8]. However, issues related to sustainability often arise where the streams of natural resources are concerned. Since our rationale for developing a multiscalar framework is tied to the issues of sustainability and resource flows, we focused on bioclusters with a strong component of natural renewable resources. Finally, we excluded the articles using the case studies only as a source of a specific type of data. For instance, a few articles retrieved and analyzed the patent data from certain bioclusters. A thorough analysis of these articles revealed that they do not serve the aims of our study and hardly ever point to any scale, level, or dimension. The articles left after applying the last inclusion criterion had a rather descriptive nature of the case studies. They described the history of the bioclusters, studied their growth, resource flows, and networks, analyzed the policy effect on cluster development, the innovativeness of clusters, and their institutional structures, and so on. Applying these inclusion criteria yielded 42 cases reported in 35 articles.

3.3. Description of the Sample of the Case Studies

We would like to shortly reflect on the location of the bioclusters in our set of articles and on the bioeconomy sectors they cover. The 42 bioclusters reported in this paper were localized in 20 countries in different parts of the world. Figure 3 presents the global distribution of the bioclusters in our sample of articles.

Seven countries in Europe were the focus of 24 case studies, thus representing a higher frequency of cases relative to the other countries, and a higher concentration in that geographic region. Outside of Europe, all of the countries, with the exception of the USA and Chile, were the focus of one single case study. This means that there seems to be a significant bias in the spatial distribution of the 42 bioclusters in Figure 3, and the distribution of bioclusters is not representative of all the bioclusters on the planet.

The case studies in our sample of articles specialized in different bioeconomy sectors. We grouped our case studies into six sectors. These are presented in Figure 4.

Figure 3. Localization of the 42 bioclusters described in the set of the articles.

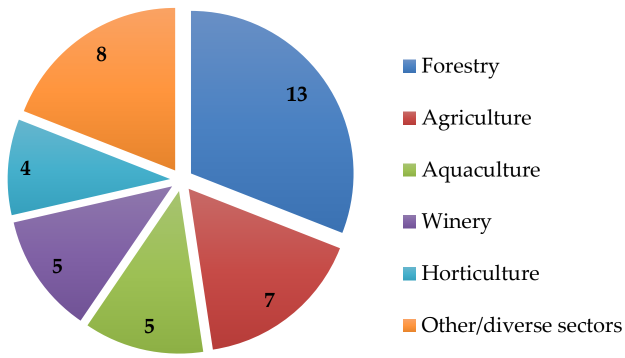

Figure 4. Distribution of the bioeconomy sectors among the bioclusters in the set of the articles.

Forest bioclusters, with 13 cases, were prevalent among the case studies. The other sectors were agriculture (seven cases), aquaculture (five cases), wineries (five cases), and horticulture (four cases). The remaining eight bioclusters had either a broad spectrum of bioeconomy sectors or represented a sector that occurred only in that single case study. As it was the case with the spatial distribution of the 42 bioclusters (Figure 3), the distribution in Figure 4 represents neither the whole spectrum of bioeconomy sectors nor their relative sizes.

3.4. Data Extraction

3.4.1. Developing the Multiscalar Framework

The construction of the multiscalar framework was an iterative process combining top-down and bottom-up approaches. Starting with a top-down approach, we adopted four scales from the literature on cluster evolution [39]: network size, networking intensity, heterogeneity, and employment. These scales represent only the cluster-internal elements. We discussed the scales of network size and heterogeneity in the theoretical section.

The scale of networking intensity measures the intensity of networking among the different actors in a cluster. The levels of this scale can take all the values between the lowest and the highest observed networking intensity. The employment scale measures the level of employment in the cluster and can involve all the levels between the lowest and the highest observed levels.

Bioclusters are also embedded into global streams of natural resources and can thus have both positive and negative sustainability effects both in their locality and at higher levels and scales. For the second category of scales, we appropriated three scales from the literature on sustainability research. These were the geographical, administrative, and institutional scales. The lower levels of these scales, e.g., "local" and "operating rules" (see Figure 2), would concern the biocluster alone, whereas the higher levels, e.g., "national" and "laws and policies," would be situated outside of the biocluster. In this way, the scales in this category will represent the connections of the biocluster to the outside world. This will allow one to study the cause–effect links at different levels and scales and, ultimately, to create awareness about the different sustainability effects of bioclusters. The initial design of the multiscalar framework is shown in Figure 5. The dimension of cluster attributes includes the scales of network size, networking intensity, heterogeneity, and employment. The dimension of cluster links to the outside world includes the administrative, geographical, and institutional scales.

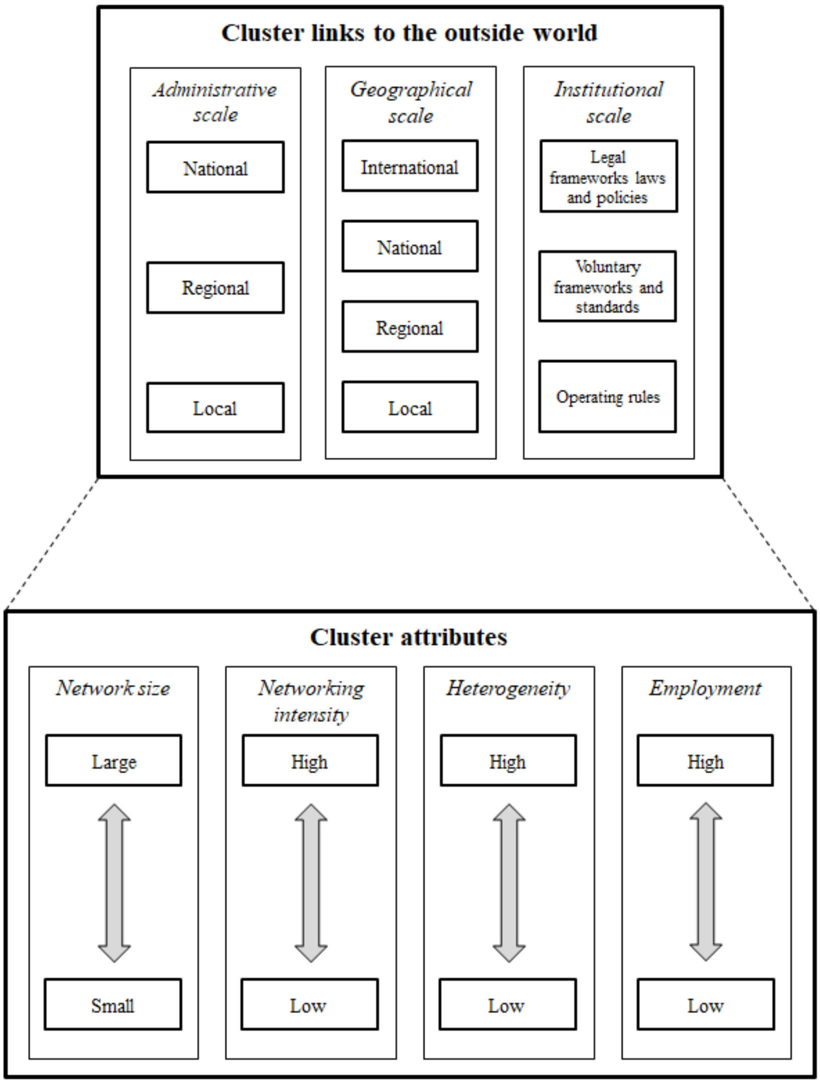

Figure 5. The initial design of the multiscalar framework.

We continued the development of the multiscalar framework with a bottom-up approach by constructing new scales retrieved from the 42 empirical cases and adding those scales to the different dimensions of the framework. The papers were analyzed by between one and three persons for the sake of increased reliability. The process of data extraction implied finding references to different scales and levels in the articles (hereafter, scale references). By "references," we do not only mean that the authors explicitly stated the importance of any particular scale. In fact, this type of reference constituted the minority of the extracted data. Most often, an extracted datum would stem from a simple reference to, or mentioning of, that scale in the process of describing or analyzing the case study. Statements from the literature were thus labeled and subsequently aggregated into a (new) scale where necessary.

During the analysis and coding of the 42 cases, we created new scales as soon as the scale references allowed differentiating among at least two levels of the scale. In this way, we added the scales of sources of natural resources, knowledge accumulation and learning, the availability of financial resources, and trust between actors. These scales are presented in Figure 6. Naturally, the articles that were analyzed before the addition of the new scales were thereafter re-analyzed for the added scales.

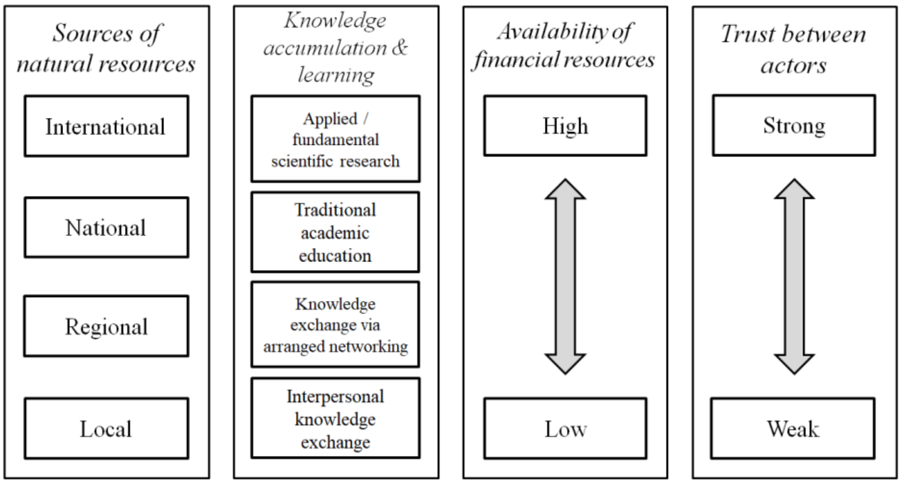

Figure 6. The new scales retrieved from the 42 case studies.

To create the final version of the multiscalar framework, we integrated the four new scales into the different dimensions of the initial framework. The scale of trust between actors was classified into the dimension of cluster attributes, because all the possible levels of this scale relate only to the actors inside the cluster. The three other scales were classified into the dimension of cluster links to the outside world. A biocluster can source its natural resources directly from its locality, or from other regions and countries. The new knowledge in the cluster can be created and exchanged via face-to-face contacts inside the cluster (local buzz), but it can also be created in universities and research centers outside the cluster (global pipelines) [49]. Similarly, the financial resources can be sourced directly among the cluster members. However, different institutions and governmental actors can also be involved in financing the cluster. Therefore, the resulting multiscalar framework is built upon an iterative process of the inclusion of scales applying both the top-down and bottom-up approaches.

3.4.2. Classifying the Sustainability Performance of Bioclusters

In line with the second aim of our study, we want to test the relationship among the economic, social, and environmental scales of bioclusters. Therefore, we included the three scales of biocluster performance into the multiscalar framework. However, the scales of economic, social, and environmental performances are not classified into any of the dimensions, because they represent a multitude of different indicators and effects. For example, the environmental performance consists of eight different types of references mentioned in 20 case studies. These were the references to environmental advantages, the use of fossil fuels, the use of renewable energies, waste utilization, environmental management, ecological effects, pollution reduction, and CO_2 reduction. The scale of social performance aggregates the references to different types of social developments, social benefits, and effects made in eight case studies. Finally, the economic performance is a compilation of multiple indicators from 37 case studies. Among these indicators were economic development, innovativeness, competitive advantage, regional or sectoral development, and marketing success. Most of these indicators were mentioned only once in all of our case studies. Therefore, it would not allow one to decide on the types of the respective scales and their levels.

It was possible to classify the case studies only according to their economic performance. This is due to the fact that the articles in our sample did not systematically discuss any social or environmental effects, whereas the "performance" of bioclusters always related to the economic performance only. Hence, the majority of our case studies provided information about economic performance, either having it as their goal or simply describing the economic performance in the course of the narrative.

Different articles described the economic performance of the bioclusters in different ways. We categorized 37 case studies along three performance levels: good, average, and poor (for the remaining five case studies, we found no information regarding their performance). Detailed information on performance levels for each case study is provided in the results section.

Some authors analyzed in their articles two or more case studies, comparing, as a rule, their performance. In these few cases, we assessed relatively easily to which performance level a case study belonged. For most of our case studies, however, an assessment of cluster performance was not the main purpose of the authors. Nevertheless, the authors of many case studies often provided obvious hints and keywords that helped us to define their performance levels. This was especially true for a few case studies with good performance levels, which operated with key phrases such as " ... leadership as a regional model and unique case study" [50], " ... a success story" [44], or " ... an image of a rising star in the wine world ... " [51]. Even in the absence of such suggestive keywords, the authors of the biocluster case studies with good economic performance levels increasingly stressed the positive aspects of the bioclusters, by describing how the clusters' performance was "good," often with respect to regional economic development, innovative capacity, enhanced competitive advantages, and regional employment.

The classification criteria were different for the bioclusters with average economic performance. Certainly, the authors did not describe how the clusters' performance was "average." Instead, they pointed, as a rule, to the important shortcomings such as weak governance, lack of trust, and potential scale challenges such as ignorance and plurality.

Finally, the case studies with poor economic performance had more pronounced shortcomings of the same nature and, most importantly, an almost ubiquitous plurality challenge described as a discrepancy of political intentions, lack of coordination, and opposite expectations at different governmental levels. In the next section, we present the results of our analysis.

4. Results

4.1. The Multiscalar Framework

Figure 7 presents our multiscalar framework. It compiles 14 scales, 11 of which are classified between the dimensions of cluster attributes and cluster links to the outside world.

The scales of economic, social, and environmental performance are grouped into cluster performance. However, we caution the reader against interpreting "cluster performance" as another dimension of scales in the framework. As a reminder, the three scales are compilations of multiple economic, social, and environmental effects. These effects can occur within the cluster alone, but they can also play out at higher geographical levels and be connected to other scales that connect the cluster to the outside world. Altogether, we found 379 scale references in the 42 case studies. Their distribution across the 14 scales is shown in Figure 8. We counted 214 references to the scales in the dimension of cluster links to the outside world. Scales in the dimension of cluster attributes were emphasized 100 times. Finally, we counted 65 references to the scales of cluster performance. It is useful to keep in mind that the distribution of the scales in Figure 8 does not imply that, e.g., the availability of financial resources or trust between actors are not very important in the bioclusters. All of the 14 scales were significant enough to be emphasized as many times as they were emphasized, whereas some of them were emphasized more than the others.

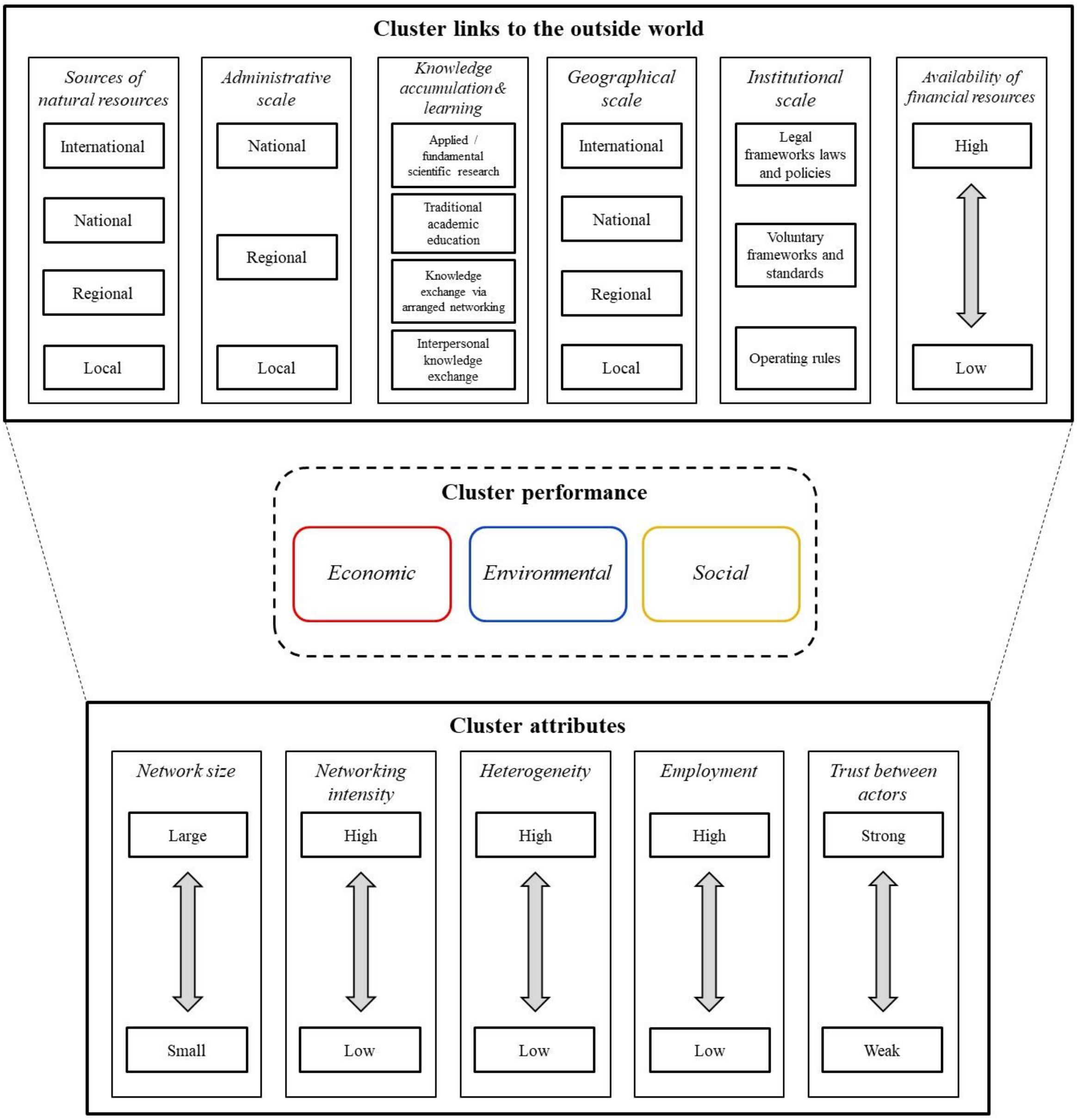

Figure 7. The multiscalar framework.

In Figure 8, the numbers specifying the scale references indicate also the number of case studies that emphasized those scales, with the exception of the knowledge accumulation and learning scale (emphasized in 36 case studies), the administrative scale (emphasized in 31 case studies), and the institutional scale (emphasized in 24 case studies). Several case studies emphasized two or more levels of these scales. For instance, a biocluster can be supported from both local and regional governments (administrative scale), or it can have knowledge flows both at the interpersonal level and through collaboration with research centers (knowledge accumulation and learning). Ultimately, a biocluster can incorporate all the levels of the institutional scale together by simultaneously involving operating rules, standards of operation, and legal frameworks. The levels in the scale of sources of natural resources were not emphasized together in any case study. Regarding the other 10 scales, their levels are exclusive in nature. For instance, the size of the biocluster network cannot be small and large at the same time. Neither can the geographical range of a biocluster be local and national simultaneously.

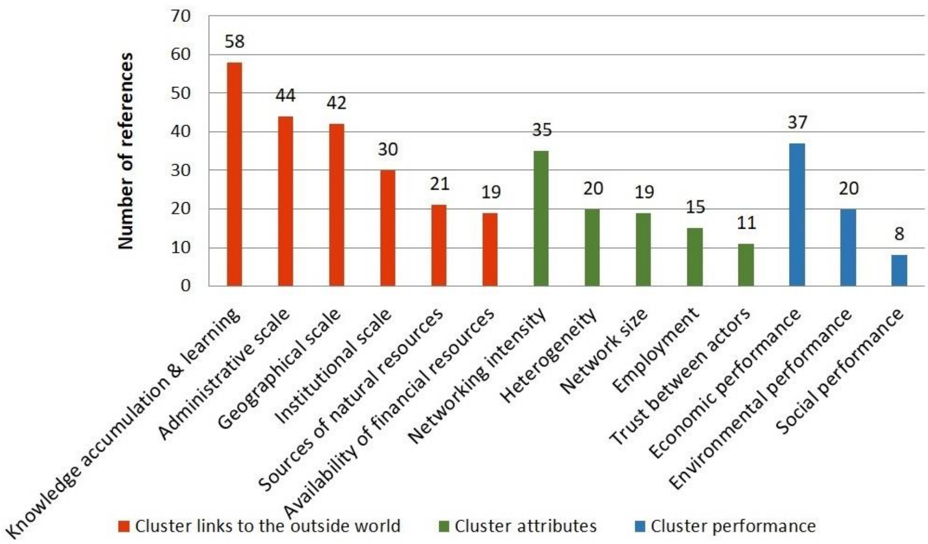

Figure 8. Distribution of the scale references across the scales and dimensions.

Below, we showcase four scales from our multiscalar framework—sources of natural resources, knowledge accumulation and learning, the availability of financial resources, and trust between actors—because they were retrieved from our case studies (see Figure 6) and not from existing theoretical literature.

The scale of sources of natural resources informs us about the geographical levels, from which the bioclusters source their natural resources. This scale was mentioned 21 times. Four case studies emphasized the local level, 14 case studies the regional level, one case study the national level, and two case studies the international level. The scale of knowledge accumulation and learning represents the different levels of formalization of knowledge exchange and learning. This scale was mentioned 58 times. With regard to the levels, interpersonal knowledge exchange was mentioned in four case studies, knowledge exchange via arranged networking was mentioned in eight case studies, traditional academic education was mentioned in 16 case studies, and applied/fundamental scientific research was mentioned in 27 case studies. For the scale of availability of financial resources, we counted 19 references. One case study emphasized the low level of this scale, and six case studies emphasized the high level. The other 12 case studies emphasized the flows of financial resources without specifying the level of their availability. Finally, trust between actors was emphasized in 11 case studies, three of which pointed to a weak level of trust between cluster actors, four to a high level of trust, and four to the importance of trust for the cluster in general, without specification of the level.

Having constructed the multiscalar framework, we can now move to the second aim of our study.

4.2. The Relationship among the Scales of Biocluster Performance

In this section, we address the second aim of our study by investigating the relationship among the different scales of biocluster performance. Table 1 lists the 42 bioclusters, the references to their economic performance, their level of economic performance, and, where applicable, their environmental and social performances.

Table 1. The case studies and their economic, environmental, and social performance.

Case Study	References to Economic Performance	Economic Performance	Environmental Performance	Social Performance
Cork cluster in Santa Maria da Feira, Portugal [52]	[cluster] is the main source of employment, added value, and exports, and the main support of this key sector in Portugal	Good	environmental benefits	social development
IAR-Pole, Hauts-de-France and Grand Est, Northern France [53]	complete innovation ecosystem on bioeconomy; largest bioeconomy network in France	Good	environmental benefits	
Forestry cluster in North Karelia, Finland [54]	(based on the comparative analysis of the cases in the article)	Good	pollution reduction	
Xylofutur cluster, Aquitaine, France [54]	(based on the comparative analysis of the cases in the article) all three segments of the triple helix model [. . .] actively included in the sectoral development; cluster organization [. . .] connects all three spheres and outreaches across sectoral and regional boundaries	Good	environmental benefits	
Forestry cluster in Baden-Württemberg, Germany [54]	(based on the comparative analysis of the cases in the article) strong sectoral organizations from all triple helix spheres	Good	utilizing renewable energies	
Bioeconomy cluster, Saxony, Saxony-Anhalt, Germany [55]	outstanding research in interdisciplinary teams; innovative industrial companies	Good	environmental preservation	
Southern and Western Catalan olive oil cluster, Spain [56]	favorable factors of Porter's diamond of national competitive advantage; successful response of agents to changing conditions	Good		
Waste Management EcoComplex, North Carolina, USA [50]	EcoComplex demonstrates leadership as a regional model and unique case study; key elements of triple helix working in collaboration	Good	striving towards zero waste	
Vegetable breeding cluster, the Netherlands [57]	this successful industry is playing important roles in the Dutch public domains; one of the most innovative in the world	Good	environmental benefits	
Paso Robles wine cluster, California, USA [51]	an image of a rising star in the wine world; a consistent increase in the number of wines and the average rating in Wine Spectator	Good		
Cluster in Horticulture, Campo de Dalías, Almeria, Spain [58]	[. . .] generating systemic and dynamic competitive advantages; the economic model [. . .] has allowed growth of both the economy and the population of Almería	Good	environmental advantages	social benefits
Wine cluster in Rioja, Spain [59]	the production of wine in Rioja has developed a successful cluster, which has fostered innovation and regional competitiveness	Good		social development
Wood cluster, Holmes, northeastern Ohio, USA [60]	unusual competitive success; the presence of this successful [. . .] cluster helps sustain regional forest-based economies	Good		
Wood waste processing cluster, Maniwa, Okayama Prefecture, western Japan [44]	the social capital [. . .], the attitude and values [. . .], institutions, and their relationships, contributed to the economic and social development, as well as environmental preservation, thus turning the Maniwa model to a success story	Good	CO_2 reduction	social development
Furniture cluster, Brianza area, Italy [61]	the district of Brianza [has] a leading position in the production of high-quality furniture	Good		
Forest and wood-processing cluster in North Rhine-Westphalia, Germany [62]	[cluster] is of nationwide and international relevance; highly significant for the regional economy and employment market	Good	environmental advantages	
Salmon industry cluster, Tenth region, Chile [63]	(based on the content of the article—no specific references)	Good	reduced environmental impact	
Agroindustry cluster, Curicó and Talca, Chile [63]	(based on the content of the article —no specific references)	Good		
Tilapia production cluster in Olancho, Honduras [64]	successful adoption and retention of tilapia culture; [. . .] facilitates technology adoption, production success, and marketing competence for all its members	Good		
Sustainable agribusiness cluster, Kuningan District, West Java, Indonesia [65]	the multi-stakeholders [of the] cluster should develop better relationship, [. . .] communication, [. . .] collaboration; some parties still doubt and lack of trust (potential plurality challenge)	Average	environmental advantages	social benefits

Table 1. *Cont.*

Case Study	References to Economic Performance	Economic Performance	Environmental Performance	Social Performance
Bioeconomy Campus, Tarvaala, Northern Central Finland [66]	somewhat lagging within the existing industrial structure; lacks the specificity of a distinct cluster and [. . .] a market-driven perspective	Average		
Wine cluster in Valle del Maule, Chile [67]	(based on the comparative analysis of the cases in the article)	Average		
Wine cluster in Serra Gaúcha, Brazil [67]	(based on the comparative analysis of the cases in the article)	Average		
The Canal Zone, Zeeland, The Netherlands [68]	occasional lack of government support; occasional difficulties in creating a cluster	Average	reduction of environmental impact	
Maine-et-Loire Horticultural Cluster, Angers, Anjou Region, Western France [69]	incompatibility between the industrial strategies of national and regional governments and local economic reality (potential plurality challenge)	Average		
Shrimp processing cluster, Soc Trang Province, Vietnam [70]	lack of public awareness and community action (ignorance challenge)	Average	reducing pollution, protecting natural resources	
Forestry cluster, Kouvola, Southeast Finland [71]	policy instruments have [not] succeeded in [. . .] systematically encouraging operators toward symbiosis-like activities	Average	environmental benefits	
Bordeaux Wines Terroir Cluster, France [72]	(based on the content of the article—no specific references)	Average		
Nelson/Marlborough seafood cluster, Upper South Island, New Zealand [73]	incomplete local supply chain; inadequate educational programs	Average	contributed to slowing down the serious exploitation facing fisheries	social development, responsibility towards social and cultural conditions
Agroindustry cluster, Piceno district, the Marche Region, Italy [74]	(based on the content of the article—no specific references)	Average		
Mechanical wood processing industry, Eastern Finland [75]	poorly structured production network, resulting in inefficient production processes; lack of trust	Average		
Dairy cluster in Nueva Guinea, Nicaragua [76]	issues related to weak governance and an absence of necessary policies and programs	Average		
Hassan Biofuel Park, Karnataka, India [77]	plurality challenge—discrepancy in the political intentions of different governmental levels regarding biodiesel: [. . .] while India's national and Karnataka's state-level biodiesel policies set blending targets as their main priorities, the Hassan Bio-Fuel Park project is heralded by policy-makers for its intention to contribute to the eradication of rural poverty without affecting food production	Poor		
Basque Country Wood cluster, Spain [54]	(based on the comparative analysis of the cases in the article) plurality challenge—complicated administrative system and a lack of trust and co-operation among the various stakeholders; governmental actors seem to be very weak when it comes to innovation support [. . .] which is a severe obstacle for developing a support system in the sector	Poor		
Catalonia Wood cluster, Spain [54]	(based on the comparative analysis of the cases in the article) weak sectoral innovation system	Poor		

Table 1. *Cont.*

Case Study	References to Economic Performance	Economic Performance	Environmental Performance	Social Performance
Agroindustry cluster in horticulture in Sinaloa, Mexico [78]	plurality challenge—lack of coordination among different administrative levels of government; weak economic effects, adverse social and ecological effects; [. . . we have enough elements to qualify Sinaloa as a dysfunctional territory . . .]	Poor	adverse ecological effects	adverse social effects
Floriculture cluster, Maumee Valley, Ohio, USA [79]	persistent social and cultural barriers and [problems breaking the traditional values and business models]; plurality challenge—[the expectations of policy makers may not coincide with industry participants]; opposite expectations and perception between policy-makers and local stakeholders	Poor		
Québec coastal maritime cluster, Canada [80]		no data		
Rizhao Economic and Technology Development Area, Rizhao, China [81]		no data	striving toward minimal use of raw materials and energy, minimal production of waste and emissions	
Biobased Economy Park, Cuijk, The Netherlands [82]		no data	CO_2 reduction	social advantages
Broad specialization cluster, Flemish-Dutch Delta, The Netherlands [83]		no data		
Textile/clothing cluster, Como, Italy [61]		no data		

Altogether, we counted 19 bioclusters with good economic performance, 13 bioclusters with average performance, and five bioclusters with poor performance. The remaining five bioclusters were not classified due to an absence of data on their economic performance.

Different environmental effects were emphasized in 20 case studies, whereas 8 case studies mentioned different social effects. Table 2 shows the results of testing the scales of environmental and social performances of our multiscalar framework against the three economic performance categories of bioclusters. Since there are different numbers of case studies in each economic performance level, we present the prevalence of the environmental and social scales not in absolute but rather in relative terms. The percentages in Table 2 denote the share of case studies in the given economic performance category that emphasized the respective scale. Positive environmental performance was observed in 63% of bioclusters with good economic performance, in 38% of bioclusters with average economic performance, and in none of the bioclusters with poor economic performance. Positive social performance was observed in 21% of bioclusters with good economic performance, in 15% of bioclusters with average economic performance, and in none of the bioclusters with poor economic performance.

Table 2. Relationship among the different scales of biocluster performance.

Scale	Economic Performance		
	Good	Average	Poor
Environmental performance	63%	38%	20% *
Social performance	21%	15%	20% *

* the percentages reflect the one case study [78] with negative environmental and social effects.

As can be seen, the scales of environmental and social performance are associated more with bioclusters in the average and, especially, good economic performance level. Within our results, we observed no positive environmental or social effects in the bioclusters with poor economic performance.

5. Discussion

In this section, we discuss the implications of our results by addressing the multiscalar framework we developed and the different correlations, overlaps, and dependencies between the scales of the framework. At the end, we discuss the limitations of our study.

5.1. Multiscalar Framework and its Application

We designed our multiscalar framework to allow studying bioclusters from the viewpoint of the cause–effect links that the different sustainability effects can have across different scales and levels. The multiscalar framework is a combination of scales and levels that are based both on the existing theoretical literature and on the 42 empirical case studies. Therefore, the multiscalar framework is a response to different authors calling for more attention to the process of inclusion and exclusion of different scales [33–35]. However, applying the concepts of scales and levels to the analysis of the empirical literature on bioclusters produced a number of overlaps and correlations between the scales. For the future applications of our multiscalar framework, it might be important to be aware of these overlaps and correlations. We thus reflect on them by conducting a correlation analysis between the 14 scales of our multiscalar framework.

In Table 3, we show the results for the Pearson's correlation coefficients of the 14 scales. If the correlation between any two scales is significant, the two scales were often emphasized together in the case studies.

Table 3. Pearson correlation matrix for the 14 scales.

	Sources of Natural Resources	Administrative Scale	Knowledge Accumulation and Learning	Geographical Scale	Institutional Scale	Availability of Financial Resources	Economic Performance	Environmental Performance	Social Performance	Network Size	Networking Intensity	Heterogeneity	Employment	Trust between Actors
Sources of natural resources	1													
Administrative scale	0.11	1												
Knowledge acc. and learning	0.11	0.04	1											
Geographical scale	-	-	-	1										
Institutional scale	0	0.02	0.02	-	1									
Availability of financial resources	0.05	0.35 *	0.25	-	0.42 **	1								
Economic performance	0.22	0.02	0.16	-	−0.04	−0.11	1							
Environmental performance	0.19	0.51 **	−0.14	-	0.05	0.28	0.06	1						
Social performance	0	0.04	0.13	-	0.11	0.41 **	−0.01	0.39 *	1					
Network size	0.14	−0.16	−0.07	-	−0.23	−0.06	0.04	−0.2	0.17	1				
Networking intensity	0.06	−0.05	0.4 **	-	−0.17	−0.11	0.43 **	−0.21	−0.11	−0.11	1			
Heterogeneity	0.1	−0.05	0.34 *	-	0.05	0	−0.09	−0.15	0.02	0.19	0.17	1		
Employment	0.25	0.19	0.24	-	−0.05	0.52 **	−0.03	0.18	0.4 **	−0.08	0.2	−0.01	1	
Trust between actors	−0.05	−0.16	0.11	-	0.01	−0.11	−0.12	−0.24	0.12	0.22	−0.02	−0.03	−0.22	1

* correlation is significant at the 0.05 level (two-tailed); ** correlation is significant at the 0.01 level (two-tailed). The correlations for the geographical scale are not available because this scale was emphasized only once in all the 42 case studies.

We observed two significant correlations between the scales in the dimension of cluster links to the outside world. These were the correlations between the administrative scale and availability of financial resources ($p < 0.05$), and between the institutional scale and availability of financial resources ($p < 0.01$). No significant correlations were observed between any scales in the dimension of cluster attributes. All the other significant correlations appeared between the scales in different dimensions and with/within the scales of biocluster performance.

The scales of networking intensity and knowledge accumulation and learning have a significant correlation ($p < 0.01$). Only 7 of the 42 case studies emphasized one of these scales without emphasizing the other. However, it is important to consider the possible overlaps between the levels of these scales (see Figure 7). For instance, all the levels in the scale of knowledge accumulation and learning on their own assume "networking." Another potential overlap can be noticed between the scales of employment and social performance that were significantly correlated ($p < 0.01$). Women employment in certain economic sectors, as well as employment of vulnerable groups in general, are considered as part of the social performance and social sustainability [84]. Despite the overlaps, these scales measure different aspects of clusters and are situated in different dimensions of our framework. Another significant correlation can be observed between the environmental performance and the administrative scale ($p < 0.01$). Our results suggest that positive environmental effects were often emphasized together with many administrative levels in bioclusters.

The scales of social and environmental performance show positive correlation ($p < 0.05$), meaning that these scales were frequently considered together in the case studies. However, it does not mean that these case studies systematically elaborated on the different social and environmental effects. A closer look at the case studies reveals that the references to the different social and environmental effects often occurred incidentally without further information on the causes or magnitudes of these effects. Furthermore, the social effects were often superficially emphasized together with environmental effects in the same sentence. On the other hand, the economic effects were discussed systematically in most case studies. Therefore, there is an asymmetry of treatments of the economic, social, and environmental aspects of bioclusters in the empirical literature. This might be due to the fact that cluster studies, generally, are conducted within the field of economic geography, which on its own is an economic discipline.

Despite the fact that there was little discussion in the case studies in the social and environmental sense, we found that the case studies with average and, especially, good economic performance were more likely to include different environmental and social benefits. However, since we have only 19, 13, and 5 cases in each economic performance category, we do not make any inference about the causal relationships among the three performance scales.

5.2. Limitations and Future Research

The literature used for this meta-analysis was rather unbalanced with respect to the roles of economic, social, and environmental effects of bioclusters. Consequently, our multiscalar framework in its present state is not a tool to assess sustainability. Instead, it is a tool that maps the different scales and dimensions to help with the assessment of different sustainability effects, if these effects are separated and presented as scales in future studies. Depending on the researched processes and the discipline, different scales might become important [33]. Therefore, applying our framework to a particular biocluster would require retrieving the necessary sustainability effects, presenting them as scales, and categorizing them either to the dimension of cluster internal elements, or to the dimension of cluster links to the outside world. This will allow one to study the interplay of different sustainability effects of bioclusters across different levels, scales, and dimensions.

One important aspect that has not been included in the different scales that we identified is that of the temporal scale. Certain events can generate both short- and long-term effects, but currently, the framework does not really identify such a scale. One way this can be achieved in future research is by conducting a longitudinal study of one or more bioclusters. A history of a biocluster can be interpreted as a development across different scales, levels, and dimensions. As a cluster moves through different development stages, for instance, according to the cluster life cycle model [39,85], its performance, as well as the scales and levels involved, are likely to change. Thus, in a longitudinal research design, the temporal effect of certain developments could be studied. In addition, such a longitudinal analysis would also make it possible to address another weakness of the current study and the difficulty this framework has in identifying causal relationships in scale dynamics. Although we discovered that different levels of economic performance of bioclusters are associated with different social and environmental performances, their cause–effect relations still need to be addressed.

6. Conclusions

In this paper, we introduced a multiscalar framework that can help to assess the sustainability effects of bioclusters. We argue that the application of this framework will increase awareness about the different scales and levels and their interactions, and will help to minimize the negative scale effects in the process of biocluster development. We tested the multiscalar framework to investigate the interrelation among the economic, social, and environmental performance scales of bioclusters. We found that, within our results, the case studies with better economic performance were more likely to include different environmental and social benefits.

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The role of sustainability in the emergence and evolution of bioeconomy clusters: An application of a multiscalar framework

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Abstract:

Bioeconomy clusters, besides stimulating economic and innovative performance, are expected to promote sustainable regional development. Despite their growing popularity, there is still a lack of awareness about how these clusters contribute to sustainability. This paper aims at increasing our understanding of the processes through which bioeconomy clusters generate sustainability effects and promote the bioeconomy transition. We analyze the event-history of the French Bazancourt-Pomacle cluster and interpret its development as a continuous interplay among its geographical, institutional, and structural scales to capture how these dynamics eventually affect specific sustainability scales. The results of the scale analysis reveal that the actors of the biocluster maintain a certain mode of action by organizing their activities along scales related to the valorization of local natural resources, whereas improvements of sustainability appear as a posteriori result of these activities rather than an aim in itself. Our study contributes with novel insights to the literature on sustainability transitions and clusters as well as demonstrates the potential of the scale-perspective for identification and measurement of sustainability trade-offs in a way accessible to policy makers.

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From local markets to global legitimacy: A bottom-up perspective on technological innovation system's dynamic

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Abstract:

The Technological Innovation Systems (TIS) literature has made considerable strides in exploring the spatial aspect of technological innovation dynamics over the past decade. Abandoning the purely national focus on TISs, scholars have theorized TIS dynamics simultaneously along multiple geographical scales, such as regional, national, and global. However, the local scale has been largely ignored in this field. This paper addresses this gap by conceptualizing a new spatial perspective on TISs, focusing primarily on the local scale which interacts with broader scales through spatial couplings. We illustrate our TIS perspective with a case study on the evolution of a particular local scale of the global biorefining TIS. Using event-history analysis, we explore how this local scale, represented by a biorefinery-based cluster, evolved through spatial couplings with different broader scales. The results reveal shifting configurations of TIS functions at various scales in different periods. While the key role of the regional scale was described by providing guidance and investments, broader spatial scales took over more diverse and flexible roles by forming markets for and disseminating the legitimacy of the local scale. The study yields new insights regarding market formation and legitimation processes in biorefining TIS. Stimulating biorefinery-internal markets and disseminating local success stories at broader scales are identified as important policy targets.