

Ayrapetyan, David; Befort, Nicolas; Hermans, Frans

**Article — Published Version**

## From local markets to global legitimacy: A materialization perspective on technological innovation system's dynamics

Research Policy

**Provided in Cooperation with:**

Leibniz Institute of Agricultural Development in Transition Economies (IAMO), Halle (Saale)

*Suggested Citation:* Ayrapetyan, David; Befort, Nicolas; Hermans, Frans (2025) : From local markets to global legitimacy: A materialization perspective on technological innovation system's dynamics, Research Policy, ISSN 1873-7625, Elsevier, Amsterdam, Vol. 54, Iss. 1, <https://doi.org/10.1016/j.respol.2024.105130> , <https://www.sciencedirect.com/science/article/pii/S0048733324001793>

This Version is available at:

<https://hdl.handle.net/10419/303492>

**Standard-Nutzungsbedingungen:**

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

**Terms of use:**

*Documents in EconStor may be saved and copied for your personal and scholarly purposes.*

*You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.*

*If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.*



<http://creativecommons.org/licenses/by/4.0/>



# From local markets to global legitimacy: A materialization perspective on technological innovation system's dynamics

David Ayrapetyan<sup>a,\*</sup>, Nicolas Befort<sup>b</sup>, Frans Hermans<sup>a</sup>

<sup>a</sup> Leibniz Institute of Agricultural Development in Transition Economies (IAMO), Theodor-Lieser-Str. 2, 06120 Halle (Saale), Germany

<sup>b</sup> NEOMA Business School, Chair in Bioeconomy and Sustainable Development, The World We Want AoE, 59 rue Pierre Taittinger, 51100 Reims, France

## ARTICLE INFO

Original content: [Supplementary Data From local markets to global legitimacy: A materialization perspective on technological innovation system's dynamic \(Original data\)](#)

### Keywords:

Local scale  
Materialization  
Technological innovation system (TIS)  
Biorefining  
Case study

## 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. Yet, the conceptual and empirical insights on the local scale of TISs have been limited. This paper elaborates a local spatial perspective on TISs and elucidates how the local scale interacts with broader scales through structural couplings. We use technological materialization to define the local scale and illustrate our perspective with a case study on a local biorefining TIS evolution in France. Using event-history analysis, we explore how the local scale evolved through functional interactions both within and across the local and broader scales. The results reveal shifting configurations of TIS functions and their interactions at various scales in different periods: while the local scale was characterized by materialization of biorefining technology and local market formation, broader scales played more versatile roles by providing resources to, forming end markets for, and establishing the legitimacy of the local scale. Policy should promote biorefinery-internal markets through technological materialization and disseminate local success stories at broader scales.

## 1. Introduction

Over the past decade, the literature on Technological Innovation Systems (TIS) has been following a particular line of theorizing, encouraging to follow the TIS-relevant actors, networks, and processes to wherever they lead at various geographical scales (Coenen et al., 2012; Binz et al., 2014). Having emerged from the criticism of predominantly national TIS perspective (Markard et al., 2012), this line has motivated scholars to develop various multiscale conceptualizations of TISs by introducing various geographical scales. For instance, authors have studied different TISs from *primarily* regional (Rohe, 2020; Rohe and Mattes, 2022), *primarily* national (Binz et al., 2012; Dewald and Fromhold-Eisebith, 2015), or even *primarily* global (Binz et al., 2014; Yuan and Li, 2021) perspectives, while using other, secondary, scales to investigate their effect on these primary scales. Furthermore, studying 'vertical' (Rohe, 2020) or 'structural' couplings (Bergek et al., 2015; Binz and Truffer, 2017), authors have elaborated on various ontologies of multiscale interrelations taking place among the primary and secondary scales.

In spite of remarkable advances in increasing the spatial sensitivity

and resolution of the TIS framework, a lacuna regarding the local scale of TISs remains open as there have been no studies on multiscale TIS that treat the local scale as *primary* and analyze its dynamics with broader scales. In this paper, we elaborate a new spatial perspective on TISs with a *primary* focus on the local scale which connects to all broader, i.e. secondary, scales. To do this, we define the local scale based on the process of technological materialization and illustrate our perspective with a case study on the evolution of a local BioRefining Technological Innovation System (BRTIS) in France. The issue of materiality has gained increasing attention, especially in the literature on the bioeconomy and biorefineries (Birch and Calvert, 2015; Van Assche et al., 2022). We will argue that incorporating the place *where technological materialization occurs* will allow us to refrain from any a priori spatial delimitations (Coenen et al., 2012; Binz et al., 2014), thereby separating the local from other scales.

Starting from the local scale, we distinguish between local functional dynamics and structural couplings with broader scales. The local functional dynamics are the interactions of TIS functions taking place among the actors within the local TIS, i.e. within the local scale. A structural coupling is attained "if specific actors, actor networks or institutions

\* Corresponding author.

E-mail addresses: [ayrapetyan@iamo.de](mailto:ayrapetyan@iamo.de) (D. Ayrapetyan), [nicolas.befort@neoma-bs.fr](mailto:nicolas.befort@neoma-bs.fr) (N. Befort), [hermans@iamo.de](mailto:hermans@iamo.de) (F. Hermans).

span across or overlap between various subsystems, be this in a specific region or country, in a global non-governmental organization or a transnational corporation” (Binz and Truffer, 2017, p. 2). Structural couplings are thus the multiscale<sup>1</sup> interactions of TIS functions taking place between the actors at the local TIS and actors situated at broader geographical scales, i.e. regional, national, European, or global (Wieczorek et al., 2015; Andersson et al., 2018). We interpret the evolution of the local BRTIS as a combination of these two types of dynamics. We are therefore interested in the evolution of the local BRTIS, shaped by how actors carry out their activities at local scale and the way they interact with actors at broader scales. Therefore, our research question is:

How did the local BRTIS evolve through a combination of local functional dynamics and structural couplings?

To answer this question, we use event-history analysis (EHA). We apply the process approach within EHA that makes a strong emphasis on temporal and causal relationships among events (Van de Ven and Poole, 2005). To study the local functional dynamics, we analyze the interactions of TIS functions that have been linked to events occurring only at the local scale. To study the structural couplings, we analyze the interactions of TIS functions that have been linked to events occurring at the local and broader scales.

Our study context is the biorefinery of the Bazancourt-Pomacle cluster (BPC) in France. This biorefinery has a 40 year history of innovations and technological materialization, making it one of the most advanced and integrated biorefineries in Europe (Thénot et al., 2018; Diakosavvas and Frezal, 2019). From the geographical perspective, the BPC operates one of the largest, yet territorial, biorefineries in the world which also transfers its expertise at the national and global scales (Philp and Winickoff, 2017). Applying principles of circular economy through a system of local by-product markets, this biorefinery produces not only biofuels and bioenergy (which correspond to most of the EU visions on biorefinery technologies (Bauer et al., 2017)), but also a wide range of bio-products such as food, feed, biochemicals, and cosmetic ingredients (Allais et al., 2021). Furthermore, unlike most European biorefineries, the biorefinery of the BPC has passed the pilot and demonstration phases, entering mass markets with most of its technologies (Philp and Winickoff, 2017, 2019). This makes the case particularly relevant for a TIS analysis, since all the TIS functions, including the processes of market formation, can be represented and analyzed. For the sake of brevity, in the remainder of the paper we refer to our case as *local BRTIS*. The TIS functions and their interactions (Hekkert et al., 2007; Bergek et al., 2008c) serve as analytical lenses for our study.<sup>2</sup>

Our study makes three contributions. First, it contributes to the TIS literature by conceptualizing a new spatial perspective on TISs based on processes of technological materialization. Second, the study generates novel insights regarding the geography of eco-innovations in TISs through a finer spatial resolution of TISs and a local perspective on TIS building (Binz and Truffer, 2017; Musiolik et al., 2020; Hansmeier and Kroll, 2024). Lastly, it opens new avenues for locally-tailored innovation policies to promote technological materialization, moving beyond the conventional policy focus on actors, networks, and institutions.

The paper proceeds as follows: Section 2 reviews the existing spatial perspectives on TISs and proposes a new local TIS perspective. Section 3 presents our case, the method, and explains the data collection and

<sup>1</sup> In TIS literature the term ‘multiscale’ has been used to indicate the existence of more than one geographical scale (e.g. regional, national, and global). Yet, other streams of literature use this term to indicate the existence of multiple types of scales, such as institutional, administrative, temporal, or other structural scales (Gibson et al., 2000; Raven et al., 2012).

<sup>2</sup> The TIS framework is not new to the literature on biorefining technology. BRTIS has been the subject of many case studies, such as by Hellsmark et al. (2016), Hansen and Coenen (2017), Giurca and Späth (2017), Frishammar et al. (2019), and Tsvetanova et al. (2022).

processing. Section 4 presents the results. Section 5 discusses the empirical, theoretical, and policy implications. Section 6 summarizes the paper and outlines avenues for future research.

## 2. Toward a local perspective in technological innovation systems

### 2.1. Definition and functions

Technological innovation system’s perspective originated from the theory of evolutionary economics (Winter and 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 and Bergek, 2011). The technology in focus can be defined either narrowly or broadly, depending on the aims and scope of the TIS analysis (Markard et al., 2015). Actors are primarily the firms within the whole value chain of the technology, but can also include other organizations, research institutes, and government bodies (Bergek et al., 2008b). Networks represent the types of relations that TIS actors establish among themselves and with other actors. These can be knowledge/research networks, political networks, as well as commercial networks linking actors to the relevant markets. Finally, institutions are the various rules and norms, both formal and informal, that regulate the interactions among the actors.

Hekkert et al. (2007) and Bergek et al. (2008a) refined the TIS concept by introducing the TIS functions. These are understood as the key processes taking place in a TIS that serve its purpose of developing, diffusing, and utilizing technology. TIS functions can influence and reinforce each other, creating various short or long functional ‘chains’ connected by causal logic. Table 1 presents and describes a set of eight TIS functions.

### 2.2. Challenging the national perspective on TISs

The TIS framework has been popular in innovation studies (Markard et al., 2015), because it can explain how (well) the development and diffusion of an emerging (often more sustainable) technology takes

**Table 1**  
A set of eight functions to study technological innovation systems.

Function	Description
F1: Entrepreneurial activities	Actors’ actions to utilize business opportunities presented by resources, knowledge, networks, and markets.
F2: Knowledge development	Applied and fundamental research on new technological options and processes.
F3: Knowledge diffusion	Networking among TIS actors pursuing joint R&D projects and the exchange of 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 to maintain and develop the TIS.
F7: Creation of legitimacy	Actors’ actions to legitimize the new technology to the government, media, and users.
F8: Materialization	Creation of TIS-related physical infrastructure such as plants, factories, and pipeline facilities.

(Source: adapted based on Hekkert et al. (2007); Bergek et al. (2008a); Bergek et al. (2008c); Suurs and Hekkert (2009); Hellsmark (2010); Hermans et al. (2019).)

place. Different TIS functions can serve as targets for policies aiming to support emerging sustainable technologies and moderate the resistance of the incumbent actors (Walrave and Raven, 2016). According to Coenen et al. (2012), the increasing tendency to inform technology policies of countries has led TIS scholars to delineate their studies predominantly to the national scale. There have been numerous case studies of TISs defined and analyzed within the boundaries of one country.<sup>3</sup> However, the tendency to define TISs nationally has faced criticism (Berkhout et al., 2009; Markard et al., 2012) as scholars began to stress that the spatial context relevant to understand technological innovations is more sophisticated. Different geographical scales, i.e. local, regional, national, global, become relevant and interrelated during innovation processes (Binz and Truffer, 2017). Focusing solely on the national scale risks overlooking important influences and effects extending beyond the national boundary as well as might ignore the different ways in which innovation processes end up distributed unevenly at the sub-national, i.e. regional and local scales (Binz et al., 2014). Consequently, scholars such as Coenen et al. (2012), Binz et al. (2014), and Miörner and Binz (2021) have called to follow the relevant actors, networks, and processes to wherever they lead instead of setting a priori spatial boundaries. These calls also tied in with discussions within human geography on the ‘politics of scale’ and ‘scale as a social construction’ (Marston, 2000; Bulkeley, 2005; Moore, 2008). These authors criticize the hierarchical nature of geographical scales that views scales as ladder containers on which the different levels form the “[...] bounded, areal units encompassing and defining the people and processes supposedly located within them” (Moore, 2008, p. 212). As a result, scholars began to implement different frameworks and methodologies, allowing them to dive deeper into the spatial complexity of technological innovation processes.

### 2.3. Existing multiscale conceptualizations of TISs

The literature on multiscale TISs can be analyzed from the perspective of primary and secondary geographical scales. This feature is critical for our study, and, therefore, we propose a distinction between primary and secondary scales to review the existing multiscale TIS perspectives and conceptualize our own. A primary scale is that from the perspective of which a given TIS is being studied. Secondary scales are those included in the analysis as well, apart from the primary scale. Fig. 1 (a–d) illustrates how different studies have conceptualized multiscale TISs using primary and secondary scales and highlights the interrelations among those scales. Following Binz and Truffer (2017) we will use term ‘structural coupling’ to characterize the interrelations among primary and secondary scales.

The global innovation systems perspective has been reified in studies that treated the global scale of TISs as primary and the national scale as secondary (Fig. 1a). Accordingly, Binz et al. (2014) conceptualized the membrane bioreactor TIS in general, i.e. at the global scale. Analyzing bibliometric data, the authors studied the spatiality of the knowledge creation processes within this technology. They found that over time the knowledge ‘flowed’ from the global knowledge pool to certain continents and, ultimately, concentrated in specific countries. Similarly, they revealed how actors created spaces of dense innovative activities that did not coincide with national borders, but instead could cross borders and shift spatial configurations over time. Following the same spatial conceptualization, Yuan and Li (2021) studied the global characteristics of battery electric vehicles TIS. Analyzing patent data, the authors revealed how the roles of technology donors and recipients are unevenly

<sup>3</sup> Some examples are the biomass digestion (Negro et al., 2007), biofuel (Suurs and Hekkert, 2009), and agricultural TISs (Hermans et al., 2019) in the Netherlands, offshore wind TIS in Germany (Reichardt et al., 2016), carbon capture and storage TIS in Norway (Van Alphen et al., 2009), wood-frame multi-storey construction TIS in Finland (Lazarevic et al., 2020), and biogas TIS in Brazil (De Oliveira and Negro, 2019).

shared among countries such as Japan, China, the U.S., Germany, and Korea, and how the distribution of these roles change over time. Binz and Truffer (2017) developed a framework to systematize the global perspective on TIS. In their framework, TIS resources, such as knowledge, markets, investments, and legitimacy can be situated at sub-global scales and interact through ‘structural couplings’. Specific resources and their multiscale dynamics can then be analyzed at transnational, national, and regional scales which over time shift and are re-defined by the relevant actor-networks and institutions.

Taking the national scale as primary, studies have focused on the national-global dynamics in TIS formation (Fig. 1b). Accordingly, Binz et al. (2012) studied the functional interactions of the membrane bioreactor TIS between the Chinese and the global context. They figured out the most probable trajectories for China to leapfrog the trial-and-error process of developed countries in implementing this technology. Building on the TIS functions framework, Andersson et al. (2018) applied a resource lens to their study on the tidal kite TIS in Sweden. They studied whether different resources such as knowledge, competence, and enabling technologies ‘stick’ more to the national or global scale during the TIS emergence.

The local, regional, national, and global scales have been integrated in studies that treated the national scale as primary and the other scales as secondary (Fig. 1c). Analyzing the processes of knowledge generation, technology production, and market formation, Dewald and Fromhold-Eisebith (2015) found that the formation of the German photovoltaic TIS could be characterized by the convergence of these processes from the local, regional and global scales to the national scale. Adopting a stricter functional approach, Nevzorova (2022) studied the development of the Russian biogas TIS, in which certain TIS functions were fulfilled more at the local, regional, or global scales with a transfer of these functions to the national scale to a greater or lesser extent.

Finally, Rohe (2020) and Rohe and Mattes (2022) paid exclusive attention to the regional scale in their studies on onshore wind TIS in different German regions (Fig. 1d). In particular, the framework of Rohe (2020) focused on the formation of the TIS resource portfolio in the German Oldenburger Land. He conceptualized ‘vertical couplings’ to study how some of the regional resources are actually created at the national and global scales, as well as emerge from local concentrations of TIS processes. Similarly, Rohe and Mattes (2022) studied the same TIS in three German regions. In particular, they revealed how the patterns of knowledge development and market formation functions vary along the regions and interact with the local, national, and global scales.

In summary, scholars have gone beyond the nationally-bound TIS perspective by choosing one primary scale, e.g. the regional, national, or global scale, and, simultaneously, considering its interrelations with secondary scales during the development of a TIS. However, none of these studies treated the local scale as the starting point for the analysis by assigning it a primary role. Moreover, the existing multiscale TIS conceptualizations (Fig. 1 a–d) still operate with pre-defined spatial boundaries for all the incorporated scales (Coenen et al., 2012).<sup>4</sup> We conceptualize a novel spatial perspective in TISs by fore-fronting the local scale and treating it as primary, while also considering its interactions with all broader, i.e. secondary, scales (Fig. 1e). In the following section, we will delve deeper into the local scale and link it to the issue of technological materialization.

<sup>4</sup> The authors of the reviewed studies referred to cities, clusters, industrial districts/complexes in relation to the local scale; to regional administrative boundaries in relation to the regional scale; to national administrative boundaries in relation to the national scale; and to the global boundary in relation to the global scale. Yet, the global scale represents a natural boundary and not an administrative one. Beyond this scale, the TIS dynamic, in principle, does not extend. Therefore, the criticism of a priori spatial delimitation in case of a global TIS perspective can be seen as an issue that has been bypassed rather than addressed directly.

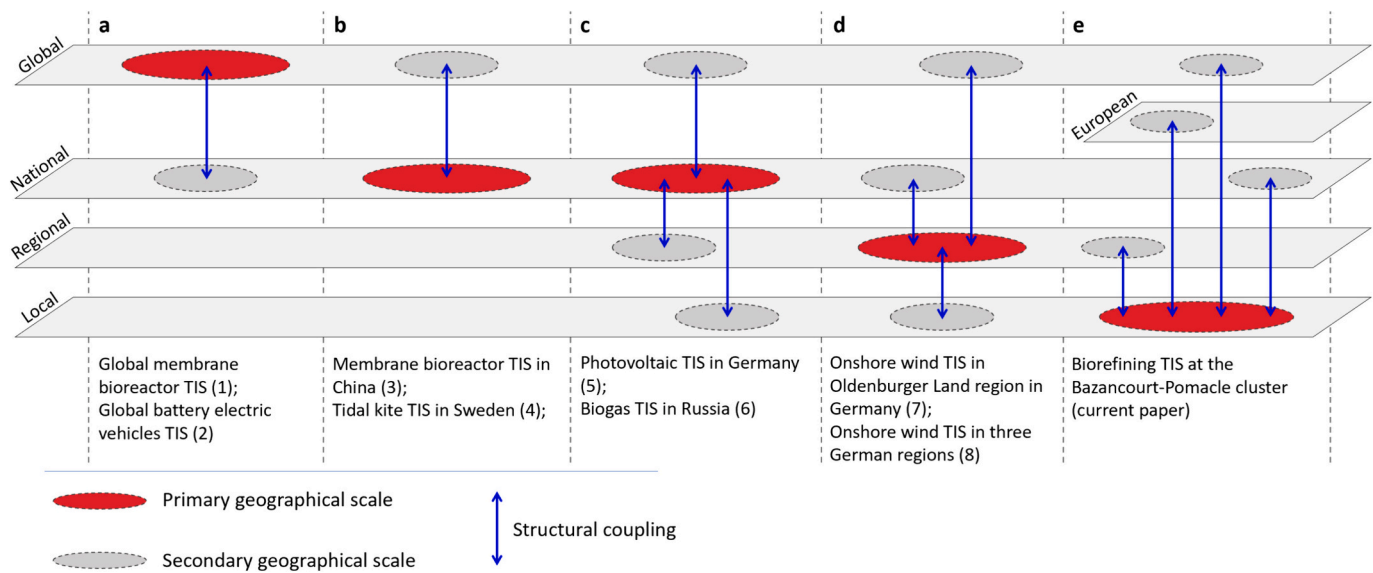


Fig. 1. Multiscalar conceptualizations of TISs in the literature (a-d) and in the current paper (e). Note: the Figure does not imply any temporal sequence along sections 'a' to 'e'.

(Sources: own elaboration based on (1): Binz et al. (2014); (2): Yuan and Li (2021); (3): Binz et al. (2012); (4): Andersson et al. (2018); (5): Dewald and Fromhold-Eisebith (2015); (6): Nevzorova (2022); (7): Rohe (2020); (8): Rohe and Mattes (2022).)

#### 2.4. The local scale in technological innovation systems

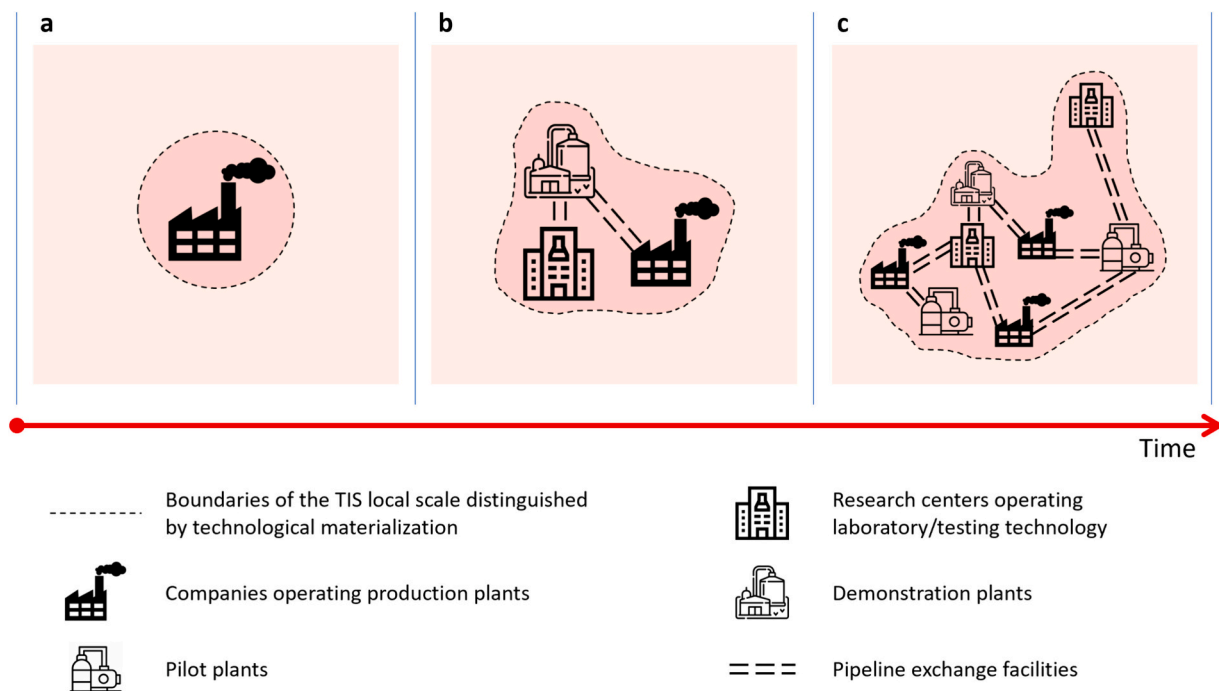
Technological innovations often emerge from distinct sub-regional localities and local networks (Coenen et al., 2012). Yet, TIS scholars often use the term 'local' to describe broader scales corresponding to specific borders such as regions and countries (c.f. Andersson et al. (2018), Rohe (2020)). Meanwhile, references to *sub-regional* local scales in TISs were made either in relation to an arbitrary local scale free from technology generating infrastructure (e.g. Lukkarinen et al. (2018), Hojckova et al. (2020)) or in relation to a regionally or nationally aggregated local scale. The latter constituted (often multiple) localities, referred to as industrial complexes, districts, clusters (Dewald and Fromhold-Eisebith, 2015; Nevzorova, 2022) as well as local concentrations of various TIS functions (Rohe, 2020; Rohe and Mattes, 2022). Yet, these were considered in the context of *primarily* regional or *primarily* national TIS perspective and can therefore be interpreted as secondary scales (see Fig. 1c and d). To resolve inconsistencies related to the terminological, geographical, and technological dimensions of the local scale, we propose a conceptual definition for the local scale in TISs.

In developing such a definition we refrain from setting pre-defined geographical boundaries such as those of a municipality, district, industrial cluster, complex, technological park, or zone (Barry, 2006). Instead, we define the spatiality of the TIS local scale through a particular *process* known as *technological materialization* in TIS literature. This process has strong parallels to place-based, i.e. local, activities and therefore serves as the foundation for our definition. Below we outline this as well as the other aspects that we integrate to define the local scale of TISs. First, based on the corresponding literature (Bergek et al., 2008c; Hellsmark, 2010; Bento and Fontes, 2015; Gosens et al., 2015; Steen et al., 2022), we interpret technological materialization as the actual coming into existence of technological infrastructure. The latter includes production plants, pilot and demonstration plants, factories, pipeline exchange facilities, as well as research centers with laboratory and testing equipment. The geographical aspect of our definition of TIS local scale is based on the process of *materialization* of this infrastructure. Thus, the local scale is 'materialized' where the corresponding technological infrastructure comes into existence. Self-evidently, we argue that this infrastructure must also be *utilized* according to the purpose of any TIS. Second, we point to the existence of a *specific institutional environment* at the local scale of a TIS. Coenen et al. (2012) and Carlsson and

Stankiewicz (1991) argue that institutional structures are consequential aspects of TISs. The rules and norms, whether informal or more formalized, coordinate the behavior of the involved actors and structure the future vision of TISs, necessary to attract resources and build legitimacy. For instance, actors involved in biorefining TISs often follow specific formal and informal rules regulating their cooperation, exchanges of by-products, and waste management (Ayrapetyan, 2023). Third, we argue that the geographical area hosting the materialized technological infrastructure must be *contiguous*, i.e. 'uninterrupted'. This is the main argument to differentiate the local scale from e.g. a regional scale. For instance, a claim could be made assuming an administrative region being distinguished by materialization of technology. Yet, in reality the technology is materialized in a number of distinct geographical areas *within* the region. These areas are not contiguous, as they are 'interrupted' by geographical space with no technological infrastructure. Therefore, each of these separate areas, and *not* the entire region, could be considered a local scale of a TIS. Lastly, we propose another simple, yet auxiliary argument to point to the sub-regional nature of the local scale: the geographical area hosting the materialized technological infrastructure must be *smaller* than the region.

Considering these four aspects, we define a local scale of a TIS as a small and contiguous geographical area operating under a specific institutional environment and distinguished by materialization and utilization of the corresponding technological infrastructure.

Fig. 2 illustrates how a local scale of a TIS can be materialized over time. It can be seen that the boundaries of the TIS local scale are distinguished based on where the technological infrastructure is materialized along the consecutive periods a, b, and c. It is important to note that, first, the distinction between the local and regional scale is a gradual one, and depends on the development phase of the TIS. This conceptualization of the local scale of a TIS can be especially helpful for the identification of the early phases of a TIS or an industrial cluster. Second, materialization is not synonymous to local. Materialization can occur in other regions or other countries and thus can occur at other scales as well. Finally, the scales are not necessarily ordered hierarchically: the local scale can have direct structural couplings with the national, or even the global scale for instance through the notion of 'globalisation' (Swyngedouw, 2004).



**Fig. 2.** Illustration of the materialization process of a TIS local scale over time. (Sources: own elaboration.)

### 3. Methodology

We employed a single case study approach (Piore, 2006; Yin, 2018) to study how the local BRTIS evolved through a combination of local functional dynamics and structural couplings. This approach offers more precise conceptual inputs through a deeper understanding and analysis of the selected case (Gerring, 2016; Gustafsson, 2017). The case of the BPC serves as a perfect example because the development of its bio-refining technology over the last 40 years was so remarkable that it is now considered as one of the most advanced biorefineries in Europe (Philp and Winickoff, 2019).

#### 3.1. The case: biorefining technology at the Bazancourt-Pomacle cluster

As of May 2022, the local BRTIS has materialized into a bioeconomy cluster commonly referred to as the Bazancourt-Pomacle cluster in France. This cluster hosts a biorefinery that integrates a number of advanced technologies of biomass valorization, conforming to the principles of integrated biorefining (Stuart and El-Halwagi, 2012). Bioeconomy clusters often operate integrated biorefineries (Ayrapetyan et al., 2022) that localize the production and processing of natural resources (Deutz and Gibbs, 2008; Ayrapetyan and Hermans, 2020). The geographic proximity of production plants, R&D centers, as well as pilot and demonstration facilities (Hellsmark et al., 2016) in such biorefineries enable the processing of biomass according to the principles of industrial symbiosis and circular economy (Vivien et al., 2019), offering potential improvements in environmental sustainability (Bosman and Rotmans, 2016; Hermans, 2021).

The biorefinery of the BPC originated from a sugar factory set up in 1953 between the communities of Bazancourt and Pomacle in the French Champagne-Ardenne region (Schieb et al., 2015). It came into existence due to the efforts of local farmers, who formed a cooperative and lobbied for its construction. For about 40 years, the site produced only sugar by operating the sugar factory. Meanwhile, its model served as an example for regional agroindustries to unite and launch bigger plants for processing wheat and alfalfa as well. Over time, due to the established markets and consistent financial support by the agricultural

bank Credit Agricole, regional farmers formed a strong dependence on the existing crops, encouraging them to continue their activities according to this biomass model (Nieddu, 1998).

Technological innovations in the use of bio-resources began in the early 1980s with the development of the chemical industry in France. In the region of Champagne-Ardenne, new firms began to specialize in developing non-food outlets from sugar beet and wheat (Grouiez et al., 2023). These firms initially operated in different locations of the region. During the 1990s, they relocated to the site of the sugar factory, forming a technologically innovative infrastructure between the communities of Bazancourt and Pomacle. In this way, the site began its transition from sugar production to a cluster operating a biorefinery. Over time, the biorefinery integrated multiple technologies allowing it to transform different types of biomass into a variety of bio-based products, such as food, feed, biochemicals, biofuels, and cosmetic ingredients.

Currently the biorefinery is a highly-industrialized area occupying a territory of 219 ha and hosting 11 firms. The industrial site directly employs 1200 people, ranging from industrial operators to researchers in the natural and social sciences, compared to around 400 people in the early 1990s. The infrastructure of the biorefinery consists of buildings, technological facilities, research centers, production plants, and pipelines owned by different actors. In terms of raw materials processing, it handles 1 million tonnes of wheat and 2.5 million tonnes of sugar beet every year. Thanks to these production capacities, the biorefinery of the BPC is Europe's 3rd largest ethanol producer. The biorefinery makes a strong emphasis on the use of the whole plant by operating a system of by-product and waste exchange, hence fully devoting itself to the idea of circular bioeconomy (Thénot et al., 2018; Morales, 2020).

#### 3.2. Event-history analysis

To answer our research question, we applied the method of event-history analysis. The choice of this method is justified for four reasons. First, events can relate to all TIS functions (Suurs and Hekkert, 2009), which is why EHA is a systematic method in this case. Second, events can happen at different geographical scales (Bunnell and Coe, 2001): from local to global. Third, during the development of a TIS, the

occurrence of certain events can explain why some later event took place (Hekkert et al., 2007). EHA, according to the process approach, gives primary importance to the temporal sequence of events, in which critical events can be pointed out and causation can be explained (Abbott, 1995; Poole et al., 2000). Hence, the interactions of TIS functions tied to events establish connections between various scales. This enables us to study how the local BRTIS evolved not only through local dynamics, but also through connections to broader scales. Fourth, this method is widely used in TIS research (see e.g. Negro et al. (2007); Suurs and Hekkert (2009); De Oliveira and Negro (2019); Hermans et al. (2019); Reichardt et al. (2016)).

The process approach within EHA gives special consideration to the chronological sequence of the events that have causal logic and eventually produce the given outcome (Van de Ven and Poole, 2005). It makes a strong emphasis on the cause-effect dynamics by accounting for different types of causalities (Poole et al., 2000): an event directly leading to another event (efficient causality), broader conditions making the event more or less likely (formal causality), events as serving the end goal (final causality), cause-effect relations between temporally proximate events (immediate causation), and cause-effect relations between temporally remote, long lasting events (distal causality). The process approach is best suited to “tell a narrative or story about *how* a sequence of events unfolds to produce a given outcome” (Van de Ven and Poole, 2005, p. 1381, emphasis added). Therefore, we adopted the process approach to study *how* the local BRTIS evolved through a combination of local functional dynamics and structural couplings. For our case, it implied constructing a chronological event-history and interpreting it according to a specific narrative (Pentland, 1999). This narrative represented the event-history of the local BRTIS from the perspective of realization of the eight TIS functions that have been linked to events taking place at different geographical scales.

### 3.3. Data collection

To construct the event-history of the local BRTIS, we used secondary and primary data sources (see Table A.1 in the Appendix A for an overview). Secondary sources involved academic literature, professional journals, websites of industrial and financial news, and websites of the actors at the local BRTIS. These were used to construct an initial event-history of the local BRTIS evolution. In addition, we analyzed the data from participatory observations and stakeholder meetings carried out by the second author over a period of ten years (2012–2022). We then complemented these data with a field work at the site of the Bazancourt-Pomacle cluster in January 2020, during which additional primary data were gathered through nine interviews conducted with different stakeholders involved in the activities of the local BRTIS (see Table A.1). The interviews lasting 45–90 min were transcribed, and the transcripts were sent to interview partners for the purpose of verification. Thirdly, the data from the final transcripts as well as from participatory observations and stakeholder meetings were triangulated with the secondary data in order to increase the reliability of the final event-history (Yin, 2018).

### 3.4. Data processing

Data processing unfolded in five stages. First, we extracted all the events (240 in total) related to technological innovations at the local BRTIS. According to Poole et al. (2000, p. 40), “events are what central subjects do or what happens to them”, and the central subjects are the entities that initiate or are influenced by the events. In our case, the central subjects were the actors involved in the technological innovation activities at the local BRTIS. Second, we arranged these events in a chronological order, creating a timeline from 1983 to 2022. Third, we divided the timeline based on the feedback from the interview partners, all of whom agreed on the existence of four evolution periods: emergence (1983–1992), shaping (1992–2003), expansion (2004–2014), and diversification (2014–2022). The interview partners also identified the

events that qualified for a beginning of a new period (see Fig. 4) representing thus major shifts in the dynamic of the local BRTIS evolution. Fourth, following the methodology of Suurs and Hekkert (2009), we assigned each event a TIS function (Table 2). Finally, we also assigned each event a geographical scale based on where the event took place. The event was assigned the local scale if it took place within the boundaries of the local BRTIS distinguished by materialization of bio-refining technology. The regional scale was assigned to events taking place in the Champagne region but outside of the local BRTIS. The national scale was assigned to events taking place in France but outside of Champagne region. The European scale was assigned to events taking place in any EU country, except of France. Events taking place outside the EU were assigned the global scale.

Having assigned each event a TIS function, we linked the pairs of events related in a causal logic to derive the interactions between the assigned TIS functions. In other words, if a certain event led to another event according to any type of causality within the process approach (see Section 3.2), then the two functions, to which we assigned these events, were connected by an arrow (see the Supplementary Data attached to this paper). Determining the causal logic between events was, in most cases, a straightforward process because the very event-history of the local BRTIS evolution involved a logical progression of events (see the Supplementary Data). Within the event-history, in most cases an event directly led to another proximate event, indicating to efficient *and* immediate causality. For the minority of cases involving events stemming from broader conditions (formal causality) as well as temporally remote events (distal causality), we determined the causal logic in coordination with the second author, who has been closely involved in the activities of the local BRTIS and could therefore provide inputs in such cases.

After deriving the interactions between the TIS functions, we determined whether such interaction constituted local functional dynamic or structural coupling. If both TIS functions were fulfilled at the local scale, their interaction constituted a local functional dynamic. If one TIS function was fulfilled at the local scale while the other was fulfilled at another scale, their interactions constituted a structural coupling.

Let us provide an example of how an excerpt from the event-history can be interpreted as a structural coupling. Consider the following excerpt: “*In 2005, national government adopts new regulations favoring the development of biofuels. Motivated by these regulations, local actors invest €272 million into the construction of a biofuel production plant.*” Two

**Table 2**  
Scheme of allocation of TIS functions to events.

TIS functions	Types of events
F1: Entrepreneurial activities	<ul style="list-style-type: none"> <li>• Firms entering TIS</li> <li>• Starting project/business</li> <li>• Business expansion</li> </ul>
F2: Knowledge development	<ul style="list-style-type: none"> <li>• Firms performing R&amp;D</li> <li>• Conducting trials/assessment studies</li> <li>• Filing patents</li> </ul>
F3: Knowledge diffusion	<ul style="list-style-type: none"> <li>• R&amp;D collaboration</li> <li>• Network creation/expansion</li> </ul>
F4: Guidance of search	<ul style="list-style-type: none"> <li>• Choosing among technological opportunities</li> <li>• Positive/negative outcomes of trials</li> <li>• Forming positive/negative technology visions</li> <li>• Devising policies/quotas</li> </ul>
F5: Market formation	<ul style="list-style-type: none"> <li>• Firms entering/creating markets</li> <li>• Obtaining market/production quotas</li> </ul>
F6: Resource mobilization	<ul style="list-style-type: none"> <li>• Mobilizing financial/human/natural resources</li> <li>• Receiving R&amp;D subsidies</li> </ul>
F7: Creation of legitimacy	<ul style="list-style-type: none"> <li>• Receiving political endorsement</li> <li>• Improving reputation</li> <li>• Lobbying to government authorities</li> </ul>
F8: Materialization	<ul style="list-style-type: none"> <li>• Constructing plants, factories, laboratory/testing infrastructure, and pipeline facilities</li> </ul>

(Source: adapted based on Suurs and Hekkert (2009) and Hellsmark (2010).)

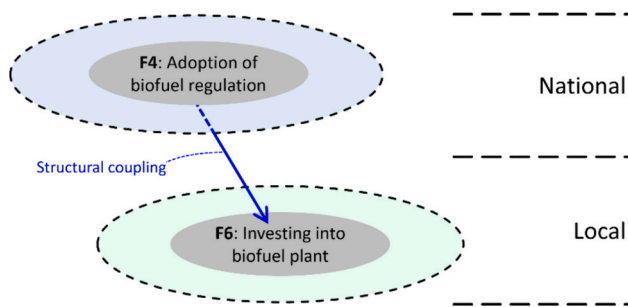


Fig. 3. An example of a structural coupling resulting from interaction of two functions fulfilled at the national and the local scales.

chronological events can be extracted from this excerpt. First event: national government adopts favorable biofuel regulation. Second event: actors at the local BRTIS invest into a new biofuel production plant. In this example, local actors were incentivized to make the investment because of the new biofuel regulation. Therefore, the first event leads to the second event, i.e. the two events are linked in a causal logic. Assigning each event a TIS function and a geographical scale will imply that guidance of search (F4) at the national scale drives resource mobilization (F6) at the local scale. From this, a structural coupling emerges between the national and the local scales (Fig. 3). The way structural couplings are derived in Results follows the same logic.

In the narratives of Results section, we quote the TIS functions in parentheses along with a letter indicating the geographical scale, where the respective function was fulfilled: L: Local; R: Regional; N: National; E: European; G: Global. For instance, ‘(F2:R)’ indicates that knowledge development (F2) took place at the regional scale (R).

#### 4. Results

Fig. 4 depicts the timeline of the local BRTIS evolution. The events marked in red signify the beginning of a new period. All the actors appearing on the timeline are listed in Table 3 along with their full names and description of their activities.

Below we present the results of the functional analysis of the local BRTIS evolution during the four development periods. We first describe the narrative of each period<sup>5</sup> followed by a summarization of its multiscalar functional dynamics. The latter are illustrated at the end of each period through Figs. 5–8.

#### 4.1. Emergence of the local BRTIS (1983–1992)

The early drivers behind the emergence of the biorefining technology in the Champagne region were the evolving markets for sugar beet and wheat products (F5:R), as well as the dependence of the regional farmers’ cooperatives on these feedstocks (F4:R) (see Section 3.1). Later in 1980s, the development of the chemical industry in France and the excess of agricultural production further guided the activities (F4:R) toward establishing a plant-based refinery in the region. These drivers led to the mobilization of considerable natural and financial resources (through regional agricultural union Champagne Céréales) (F6:R) as well as to the founding of the firms (F1:R) interested in developing new knowledge (F2:R) for non-food applications of sugar beet and wheat. The first such attempt of regional players was ADRIAC founded in 1983 to develop bio-based packaging from the residues of the feedstocks. Among other more prominent firms were Sugar Research and Development (SRD) and Ethanol Research and Development (ERD). Their research endeavors (F2:R), often realized in collaboration with other French firms and industries (F3:N), were extraordinarily fruitful (F4:R) and resulted in new technological processes for the production of bio-based DHA, hyaluronan (two key products to be marketed later by Soliance), and ethanol fuel. Eventually, SRD and ERD merged to form Agro-Industry Research and Development (ARD) in 1989 (F1:R) which since has been the nucleus of technological innovations at the local BRTIS. The prospects of developing fossil-free outlets legitimized the idea of a biorefinery (F7:R) at the Reims municipality. The latter directed financial resources (F6:R) into two new research structures: CAVISA in 1990 and Europol’Agro in 1992. CAVISA served mainly as an orientation structure (F4:R) within the new technological options, while Europol’Agro laid the basis for non-food applications of alfalfa (F2:R).

##### 4.1.1. Multiscalar functional dynamics

Fig. 5 shows the multiscalar functional dynamics of the local BRTIS evolution in the period of emergence. In this period, only local, regional, and national scales are involved. Moreover, the processes of local BRTIS emergence are taking place mostly at the regional scale which contains almost all TIS functions. Only the functions of materialization<sup>6</sup> and guidance of search are fulfilled at the local scale, leading to weak structural couplings. The local-regional couplings were defined by influence from local materialization on regional guidance of search. Meanwhile, the local-national couplings were defined by influence from national knowledge diffusion on local guidance of search.

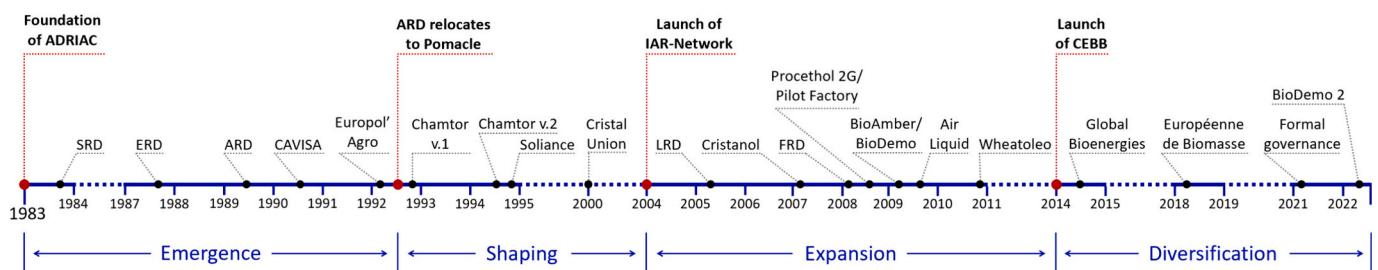


Fig. 4. Timeline of the evolution of the local BRTIS.

<sup>5</sup> For the sake of brevity, in each period we present only the condensed version of the narrative referring to the most important events and the associated TIS functions. The full event history analysis of the local BRTIS evolution can be found in the Supplementary Data attached to this paper.

<sup>6</sup> Although the sugar factory was materialized in 1953, in this particular instance we outline the fulfillment of the corresponding function F8 at the local scale during the period of emergence as well (Fig. 5). This is done to point to the existence of the local scale of the BRTIS represented only by the sugar factory.

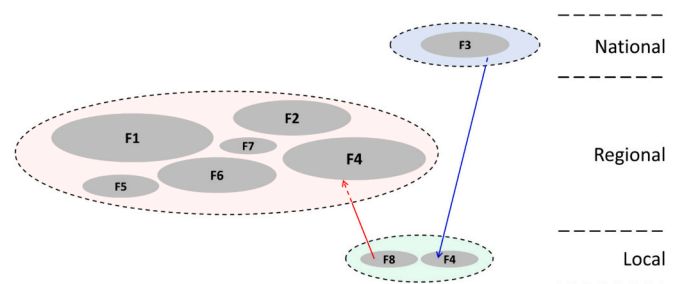


**Table 3**  
Actors involved in the evolution of the local BRTIS.

Abbreviation/ name	Full name	Description
ADRIAC	Association for the Development of Research in the Food and Packaging Industries	Company specializing in developing bio-based and biodegradable packaging for meat products
SRD	Sugar Research and Development	Research unit developing new outlets from the by-products of sugar beet
ERD	Ethanol Research and Development	Research unit exploring options for bio-ethanol production through the fermentation of sugar beet by-products
ARD	Agro-Industry Research and Development	Applied research company specialized in developing new outlets from the by-products of sugar beet and wheat
CAVISA	Centre for Analysis and Development of Agricultural Substrata	A structure uniting regional producers of sugar beet, wheat, and alfalfa to develop non-food outlets
Europol'Agro		A joint research structure conducting fundamental and applied research to develop innovative uses for agro-resources
Chamtor (v.1 & v.2)		Production plant owned by the cooperative of wheat growers – Vivescia – and specializing in obtaining fructose from chicory roots (v.1), later in transforming wheat into starch and glucose products (v.2)
Soliance		Spin-off firm of ARD developing natural active ingredients and new molecules for the cosmetics industry
Cristal Union		Agricultural cooperative of sugar beet growers
IAR-Network	Industry and Agro-resources Network	Political initiative uniting Champagne-Ardenne and Picardy regions to coordinate research projects and streamline investments
LRD	Luzerne Research and Development	Joint research unit specializing in developing food and feed products from alfalfa
Cristanol		Production plant specializing in processing sugar beet and wheat by-products into first generation bioethanol
FRD	Fiber Research and Development	R&D firm (extension of ARD) in Troyes specializing in processing hemp fibers into bio-based construction materials
Procethol 2G/ Pilot Factory		Company specializing in the production of second generation bioethanol from non-food biomass (led to the construction of pilot plant – Pilot Factory)
BioAmber/ BioDemo		Company specializing in the production of bio-based succinic acid from wheat by-products (led to the construction of demonstration plant – BioDemo)
Air Liquid		French multinational company specializing in the purification of CO <sub>2</sub>
Wheatoleo		Spin-off firm of ARD developing biosurfactants from wheat by-products

**Table 3 (continued)**

Abbreviation/ name	Full name	Description
CEBB	European Center in Biotechnology and Bioeconomy	Joint fundamental research center aiming at creating new economic value from the agricultural resource
Global Bioenergies		French company specializing in producing bio-isobutene from sugar beet by-products later in producing cosmetics and aviation fuels from derivatives of bio-isobutene
Européenne de Biomasse		French company developing new biofuel (black pellets) from wood products
Formal governance	Jacques de Bohan association of the BPC industrial territory	Structured organization coordinating the activities of the industrial, economic, and public stakeholders at the local BRTIS
BioDemo 2		Second line of the demonstration plant BioDemo with larger capacity



**Fig. 5.** Multiscalar dynamics of innovation system functions during the emergence of the local BRTIS. Note: in Figs. 5 to 8, the local scale and the associated arrows designating the local functional dynamics are depicted in green. The regional scale and the associated arrows designating the local-regional couplings are depicted in red. The national scale and the associated arrows designating the local-national couplings are depicted in blue. The European scale and the associated arrows designating the local-European couplings are depicted in black. Lastly, the global scale and the associated arrows designating the local-global couplings are depicted in yellow. The widths of the arrows are proportional to the number of times the respective functional interaction took place. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

**4.2. Shaping of the local BRTIS (1992–2003)**

The local BRTIS began to take shape in 1992 when ARD relocated to the site of the sugar factory (F1,F8:L) initiating the Bazancourt-Pomacle cluster (F3:L). Motivated by the fruitful cooperation among different sectors within CAVISA (F4:R), ARD started to develop a new process of obtaining fructose from chicory roots (F2:L). Successful laboratory trials (F4:L) led to the construction of the Chamtor plant in 1992. Located between ARD and the sugar factory (F1:L), Chamtor materialized the technological infrastructure to process chicory roots (F8:L). Simultaneously, negotiations were held with the EU to obtain market quotas for fructose (F7:E). However, due to a number of technical reasons, the market quotas were not granted (F5:E). Eventually, after major technological redesigning of Chamtor in 1994 (F8:L), the plant switched to processing wheat and formed a market for its production (pastries, cakes, bakeries) at the global scale (F5:G). Being close to the sugar factory enabled Chamtor to create product synergies. In particular, the construction of power lines and pipelines (F8:L) enabled the exchange of electricity and process water leading to the formation of an internal market between the plants (F5:L). The potential of the site to offer new

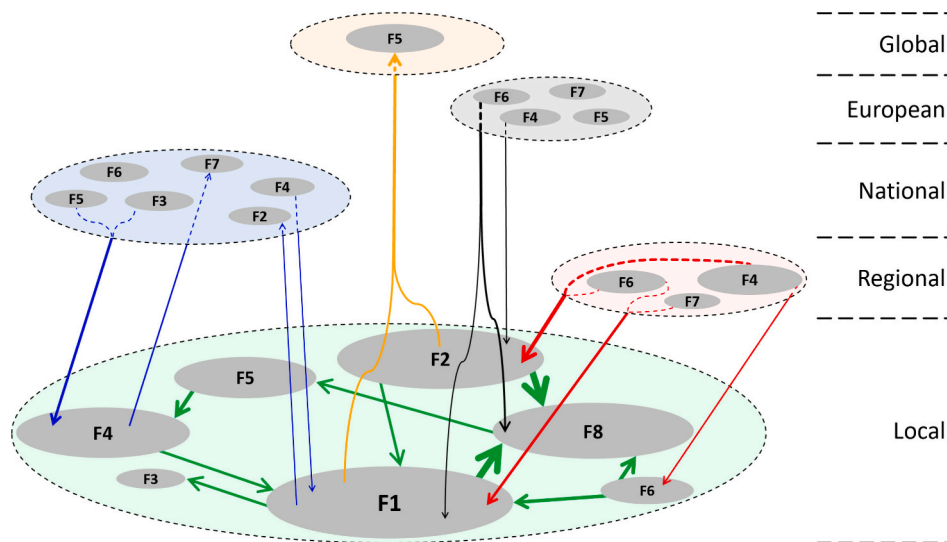


Fig. 6. Multiscalar dynamics of innovation system functions during the shaping of the local BRTIS.

synergies and attract high-tech firms provoked the interest of the national government (F7:N). The latter directed investments (F6:N) for new projects involving various French firms and universities (F3:N) encouraging the further development of the local BRTIS.

Another major achievement was marked by the creation of Soliance in 1994 as a spin-off of ARD (F1:L). Based on the previous work of SRD, Soliance launched the technology (F8:L) to process wheat by-products into non-food outlets for the cosmetics industry. Being a huge success, Soliance accessed the markets of active cosmetic ingredients, new molecules, and fragrances (F5:N) while simultaneously forming an internal market with Chamtor and ARD via deploying pipeline exchange facilities (F8:L) for glucose, steam, and water (F5:L). Soliance bolstered the actors' confidence that the future of the local BRTIS lies in *exploring and utilizing local synergies* (F4:L). This led to shaping of an initially informal institutional environment at the local BRTIS, yet remarkably guiding most of its future development.

The beginning of the 2000s saw a consolidation movement of agricultural cooperatives willing to unite capacities to face the increased international competition for agro-industrial markets (F4:N). Thus, the agricultural cooperative Cristal Union was formed in 2000 from four smaller sugar beet cooperatives. It helped to pool together human, financial, and industrial resources (F6:R), as well as pursue a diversification strategy to incorporate technologies of alfalfa processing into the local BRTIS (F4:R).

#### 4.2.1. Multiscalar functional dynamics

Compared to the first period, the configuration of local functional dynamics and structural couplings changed considerably (Fig. 6). Most of the processes of the local BRTIS development shifted from the regional to the local scale. Regarding the local functional dynamics, local guidance along with local knowledge and resources drove local entrepreneurial activities. We also observe that local entrepreneurship, knowledge, and resources created an intense dynamic of local technological materialization. The latter formed local markets that, in turn, further defined local guidance of search.

The local-regional couplings were defined mostly by regional guidance and resources driving local entrepreneurship and knowledge creation. The local-national couplings unfolded through interactions of different functions at the national scale with local entrepreneurship and guidance. The local-European couplings were defined mostly by European resources driving local entrepreneurship and materialization. Finally, the local-global couplings reflected the dynamics of global market formation driven by local entrepreneurship and knowledge.

#### 4.3. Expansion of the local BRTIS (2004–2014)

The third period of the local BRTIS evolution was a period of expansion. This expansion took place both externally and internally in terms of networks, R&D capabilities, and markets. The events at the local BRTIS guided the actors (F4:L) toward formation of new networks both within and outside the BPC (F3:L–G) as well as toward exploration of new technological opportunities through cooperation with various national and international partners. Most noteworthy was the formation of the IAR-Network in 2004 which gave the local BRTIS a national recognition (F7:N). This and other networks with industrial partners, universities, and public organizations streamlined the process of financing (F6) of new research activities and firms (F2,F1:L). As a result, the local BRTIS diversified into research on new types of biomass by transferring the model of ARD to create two more R&D firms in the region. These were the alfalfa research center (LRD) created in 2005 and hemp research unit (FRD) created in 2008 (F1:R). Their research on the new applications of plant proteins and fibers (F2:R) followed by the EU quotas for the resulting products (F5:E), enabled them to access national and European markets of food products and construction materials (F5:N,E).

Along with the said external expansion, the local BRTIS underwent pronounced internal expansion as well. This expansion was driven mostly by the previously adopted vision of exploring and utilizing new synergies among the actors. The first and most significant movement was the diversification of the local BRTIS into biofuel technologies. New French policies favoring the development of biofuels (F4:N) led to national regulations of obligatory blending in 2007 (F5:N). Anticipating these regulations, the cooperatives (Cristal Union and Blétanol) and other stakeholders invested more than €300 million (F6:L) for the construction of bioethanol production plants at the BPC. In this way, Cristanol – the plant for 1G bioethanol – was set up in 2007 (F8:L), followed by the launch of Pilot factory – 2G bioethanol – in 2008 (F8:L). Operationalizing these plants formed a number of new markets for the local BRTIS. The construction of pipelines from the sugar factory and Chamtor to the bioethanol plants (F8:L) formed internal markets for the non-crystallized sugar paste, liquid wheat, and steam (F5:L). Meanwhile, the ecological process of biomass fractionation developed for 2G biofuels was commercialized and marketed by IFPEN – the French Institute of Petroleum – in 2011 (F5:N).

Consistent with the internal expansion, the local BRTIS grew due to other technologies of biomass valorization as well. Their development followed a pathway similar to that of biofuel technologies. Guided by

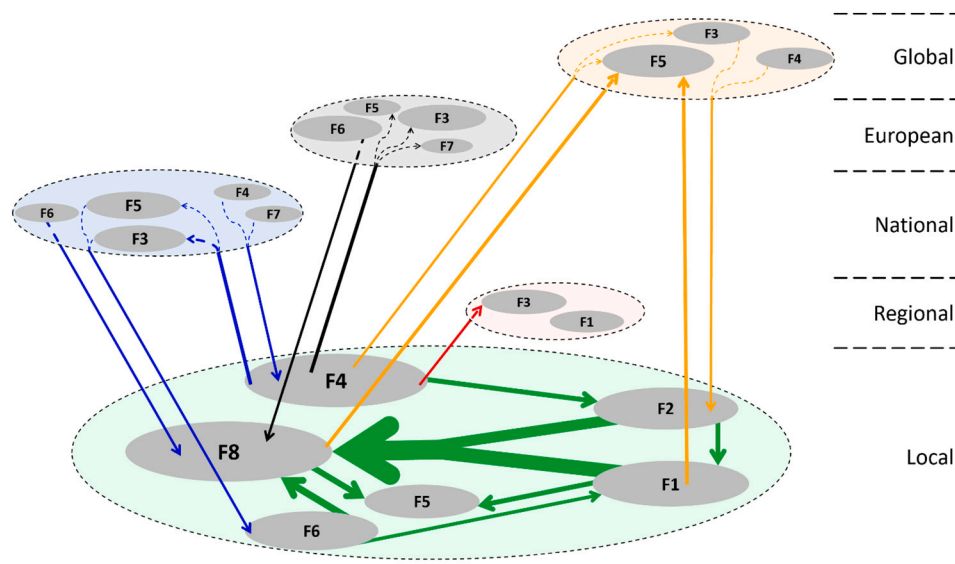


Fig. 7. Multiscalar dynamics of innovation system functions during the expansion of the local BRTIS.

novel technological foresight (F4), ARD partnered with European and other international organizations (F3:E,G) to research the properties of wheat by-products (F2:L) to convert them into bio-based succinic acid and biosurfactants. This research gave birth to BioAmber in 2009 as a joint venture between ARD and a North-American firm – DNP Green technologies – as well as to Wheatoleo in 2010 as a subsidiary of ARD (F1:L). A total of €21 million were invested by European Regional Development Fund (F6:E) for the construction of a demonstration plant BioDemo (F8:L) needed for the upscaling of the process of bio-based succinic acid by BioAmber. Wheatoleo and BioAmber accessed global markets for their products (F5:G). Meanwhile, constructing new pipeline facilities with the existing plants (F8:L) further developed the internal markets of CO<sub>2</sub>, glucose, and steam exchange (F5:L).

Finally, in 2009 Air Liquid – a French multinational company – invested into a CO<sub>2</sub> purification facility at the local BRTIS (F1:L), materializing new infrastructure to process CO<sub>2</sub> (F8:L) and enabling the local BRTIS to enter the global market of carbonated beverages (F5:G). Simultaneously, new pipelines were laid (F8:L) to source CO<sub>2</sub> from Cristanol and deliver purified CO<sub>2</sub> to BioDemo, expanding thus the local market of CO<sub>2</sub> exchange (F5:L).

#### 4.3.1. Multiscalar functional dynamics

In the period of expansion, we notice significant intensification of functional interactions both in terms of local function dynamics and structural couplings (Fig. 7). Altogether, the local functional dynamics were similar to those in the previous period. Thus, local knowledge and resources drove local entrepreneurial activities and materialization. Similarly, the latter led to formation of local markets. However, the role of local guidance in this period shifted to merely driving local knowledge creation. The local-regional couplings were defined by local guidance driving regional knowledge diffusion. Regarding local-national couplings, local guidance of search formed national knowledge networks and markets which then fed back enriching local resources. Meanwhile, national resources contributed to local materialization. The local-European couplings were defined by local guidance forming networks, markets, and legitimacy at the European scale. Meanwhile, the latter contributed resource-wise to local materialization as well. The local-global couplings were defined mostly by the formation of global markets due to local entrepreneurship and technological materialization. Lastly, global knowledge networks and guidance contributed to local knowledge development.

#### 4.4. Diversification of the local BRTIS (2014–2022)

The last period of the local BRTIS evolution was distinguished by diversification in terms of markets, knowledge, and biomass inputs. This diversification began in 2014 with the establishment of the European Center in Biotechnology and Bioeconomy (CEBB) at the site of the biorefinery (F1,F8:L). As an extension of Europol'Agro, CEBB engaged in fundamental research of agro-resources (F2:L). Its research in cooperation with multiple international partners (F3:G) underpinned the global reputation of the local BRTIS (F7:G). Concurrently, Global Bioenergies – a French company envisaging the production of bio-isobutene from sugar beet residues – joined the local BRTIS (F1:L) by constructing a 500 L pilot facility (F8:L) to upscale its technological process. Using the sugar beet by-products from the sugar factory (F5:L), Global Bioenergies together with ARD conducted trials to upscale the process (F2:L). The trials were successful (F4:L) allowing the company to mobilize €4.4 million (F6:N) in 2015 to construct a demonstration plant in Leuna, Germany (F8:E).

The diversification in terms of biomass inputs resulted from the joining of Européenne de Biomasse in 2018 (F1:L). This French company specialized in innovative technology for biofuel production from wood and wood by-products – a biomass new to BRTIS. The production required large amounts of steam for the fractionation of inputs. For that, Européenne de Biomasse constructed a combined heat and power plant (F8:L) to share the demand for steam with local actors and cover its own. Eventually, Européenne de Biomasse formed a market for the biofuel in the national urban heating network (F5:N) as well as engaged in steam exchange with the local actors (F5:L).

In 2018, the National Industry Council selected the site as an 'Industrial Territory' in the field of circular bioeconomy (F7:N), prompting the local actors to establish a formal governance to manage synergies and guide future activities. Consequently, the "Jacques de Bohan Association of the BPC industrial territory" was formed in 2021 (F1:L) to facilitate efficient resource exchange, direct investments, and promote the site (F4:L). Most importantly, this governing structure further formalized the institutional environment at the local BRTIS to *guide actors toward active collaboration as well as exploring and utilizing synergies among the existing and prospective actors*.

The strengthening global recognition of the local BRTIS (F7:G) led to its diversification also in terms of markets. Having a considerable development potential, the local BRTIS has been attracting different national actors to join the biorefinery (F4:N). Under these circumstances

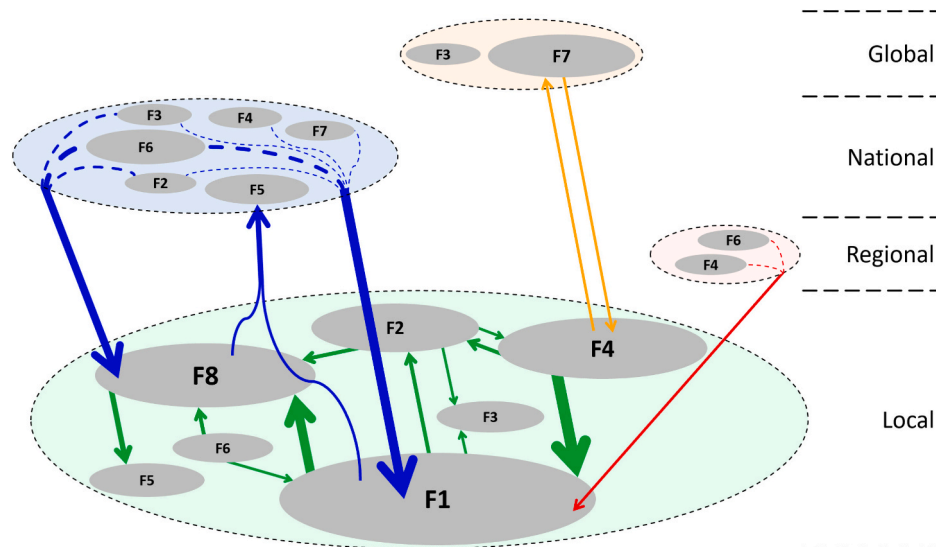


Fig. 8. Multiscalar dynamics of innovation system functions during the diversification of the local BRTIS.

and to prevent a rapid expansion of the local BRTIS beyond the current 219 ha, ARD adopted a new business model. It began to prioritize smaller projects with high added value by attracting foreign firms to upscale their production (F4:L). In 2018, ARD expanded its business by taking over the Pilot Factory (F1:L), thus creating a market for knowledge of upscaling of technological processes to the pilot phase (F5:L). Later in 2021, ARD conducted studies to enlarge the demonstration plant BioDemo (F2:L). The result was a second line of BioDemo with a capacity of 217m<sup>3</sup> installed in 2022 (F8:L). The new line expanded the market for knowledge of upscaling of technological processes to demonstration phase as well (F5:L).

#### 4.4.1. Multiscalar functional dynamics

In the period of diversification, we notice intensified dynamic in particular concerning structural couplings (Fig. 8). Local functional dynamics were similar to those of the previous two periods, with local knowledge and resources driving local materialization. The latter, along with local entrepreneurship, led to the formation of local markets. Meanwhile, the role of local guidance expanded to drive both local knowledge development and entrepreneurship. The local-regional couplings were defined only by influence from regional guidance and resources on local entrepreneurship. The local-national couplings were defined by strong influence from different functions at the national scale on local entrepreneurship and materialization. The role of national resources was the most significant in this dynamic. However, the effects of national knowledge development and networks were more tangible on local materialization. National markets, in turn, were shaped both by local entrepreneurship and materialization. Lastly, the local-global couplings were defined by a bidirectional interplay between local guidance and global legitimacy.

## 5. Discussion

### 5.1. Empirical reflection: the evolution of the local BRTIS

The conducted analysis reveals how the evolution of the local BRTIS took place through functional interactions taking place within the local BRTIS, i.e. local functional dynamics, as well as functional interactions unfolding between the local and broader scales, i.e. structural couplings. The latter had a bidirectional nature (Hojckova et al., 2020), meaning that the local scale not only received influence from the broader scales, but also extended its influence toward broader scales. We can provide an empirical answer to our research question by summarizing the local

functional dynamics and structural couplings during the four periods of the local BRTIS evolution (Fig. 9).

The local functional dynamics can be characterized by local knowledge, resources, and guidance driving local entrepreneurship and technological materialization. The latter led to consistent formation of local markets, i.e. markets of by-products. We observe slight variations in the role of local guidance of search. While being driven by local markets and advancing local entrepreneurship during the period of shaping, the local guidance switched its role to promoting local knowledge in the expansion period, while extending its influence on both local knowledge and entrepreneurship in the last period.

The local-regional couplings were defined by strong influence from regional guidance and resources on the local BRTIS during the periods of shaping and diversification. Moreover, this influence shifted over time from driving local knowledge development to driving local entrepreneurship.

Regarding the local-national couplings, we observe that local guidance and entrepreneurship interacted with markets and legitimacy at the national scale in the periods of shaping, expansion, and diversification. Over time, these interactions were marked by increasing formation of national markets and increasing ‘appropriation’ of legitimacy that has been formed at the national scale. Meanwhile, the latter shifted its influence from driving local guidance in the first three periods to driving local entrepreneurship in the last period, repeating thus the respective pattern of local-regional couplings. Lastly, we also observe the strengthening role of national resources and knowledge on local materialization, as illustrated by the respective dynamics during the periods of expansion and diversification.

The local-European couplings were similar to the local-regional couplings in the period of shaping. During the expansion period, we notice the influence of local guidance on European knowledge networks, markets, and legitimacy, implying a diffusion of the legitimization process to the European scale as well. Meanwhile, local materialization was facilitated by European resources during the periods of shaping and expansion.

Finally, regarding the local-global couplings, global markets were shaped heavily by different local processes. Local entrepreneurship, knowledge, guidance, and materialization enabled the local actors to access global markets in the periods of shaping and expansion. In the period of diversification, the global scale switched its role from creating markets to creating legitimacy for the local BRTIS, implying a further diffusion of the legitimization process to the global scale as well (Fig. B7 in Appendix B).

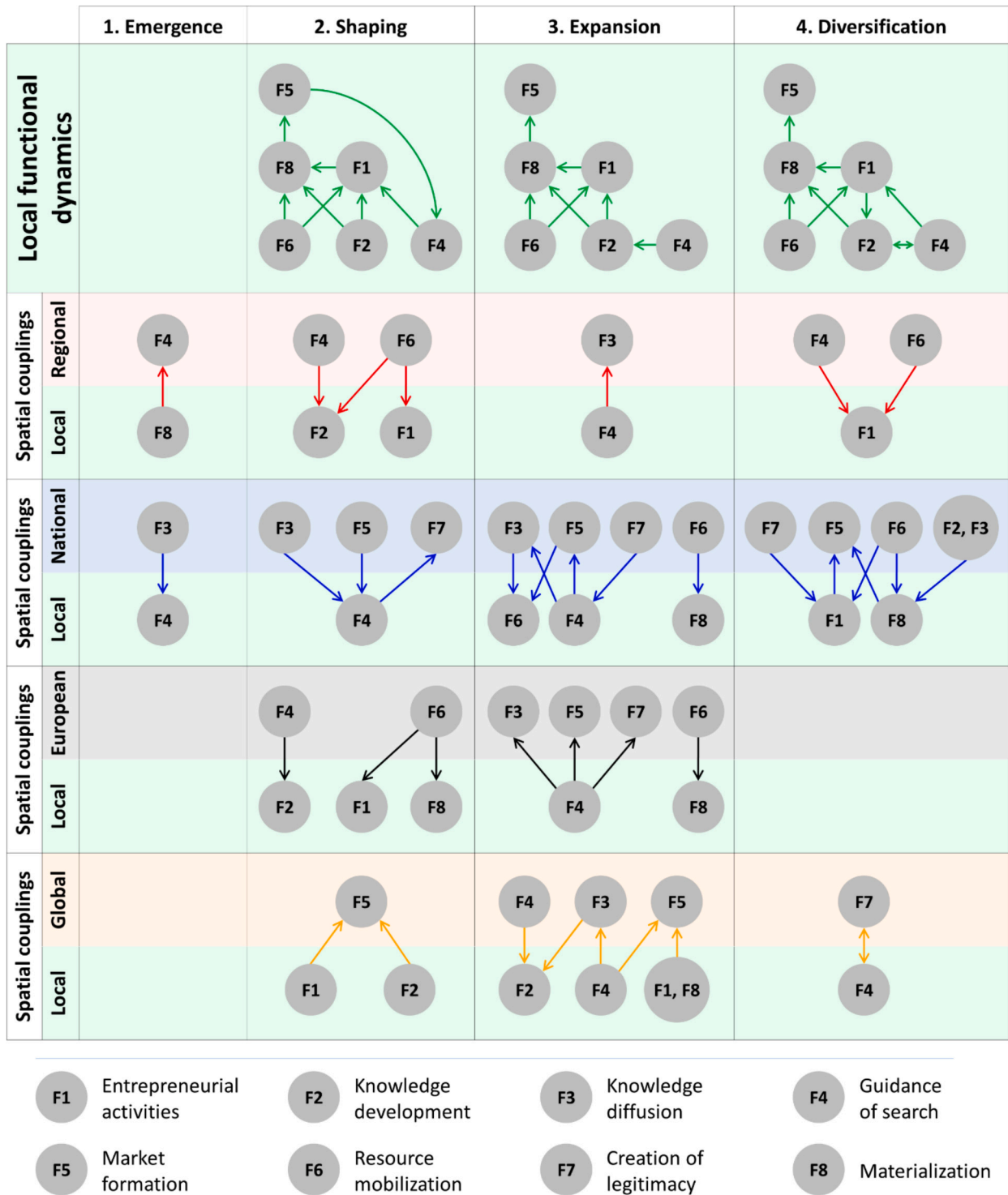


Fig. 9. Summarization of the local functional dynamics and structural couplings of the local BRTIS. Note: The first row – local functional dynamics – summarizes the interactions of TIS functions taking place only within the local scale over the four periods. Thus, the four segments in the first row depict the four excerpts of local functional dynamics derived from Figs. 5 to 8 (the top left segment is empty because we observed no functional dynamic at the local scale during the emergence period). The subsequent rows follow the same logic but relating to structural couplings. For instance, the four segments in the second row depict the four excerpts of local-regional couplings derived from Figs. 5 to 8.

### 5.2. Multiscalar resource constellations in TISs

We will focus here on the four of the seven functions that have been identified in the literature as especially relevant when the processes of TIS evolution get internationalized, crossing European and global scales: knowledge, investments, markets, and legitimacy. These four TIS

functions are often considered to be the ‘key resources’ related to the actors’ ability to access them from different geographical scales in the process of the creation of new regional paths (Binz et al., 2016; Anderson et al., 2018; Rohe, 2020; Nevzorova, 2022; Rohe and Mattes, 2022). Reflecting on the spatial dynamics of these resources is important especially in our case, in which a distinct set of few actors at the local

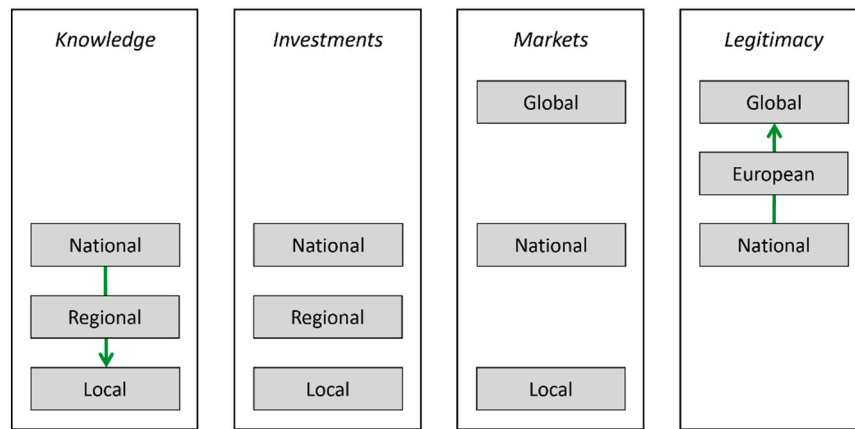


Fig. 10. The geographical dynamics of key TIS resources for building local innovation systems.

Note: in line with Binz et al. (2016), knowledge creation as a key resource stream encompasses both knowledge development and knowledge diffusion functions.

scale carried their activities through attracting TIS resources and eventually succeeded in extending their influence to the very *global* scale.

Fig. 10 presents the geographical dynamics of the four key TIS resources in the case of local innovation system building. The local actors accessed new knowledge at local, regional, and national scales, while relying more on the local scale over time (see also Fig. B2 in Appendix B). We observe the same geographical distribution with regard to investment mobilization, although without shift to any particular scale over time (see also Fig. B6 in Appendix B).

The geography of market formation indicates the formation of markets primarily at local, national, and global scales. 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 at the local scale, whereas the latter were formed predominantly at the national and global scales (see also Fig. B5 in Appendix B). These results add to the literature on market formation in biorefining TISs (Mousavi et al., 2023) as well as to the debates on spatiality of TIS markets (Dewald and Truffer, 2011, 2012; Boon et al., 2020) by distinguishing between local and extra-local market formation dynamics in biorefineries.

The local actors ‘exported’ the creation of legitimacy to national, European, and global scales, while focusing more on the global legitimation over time (see also Fig. B7 in Appendix B). Once the legitimacy of the local BRTIS crossed scales and reached the global scale, the local actors could expand their access to resources situated at regional and national scales as well. This is illustrated by the increasing effect of these scales on local entrepreneurial activities in the period of diversification, when the legitimacy of the local BRTIS reached the global scale. 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 and 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.

In general, these insights reveal the core pattern of local actors' activities, especially relating to the spatiality of market formation and legitimation processes distinguished by their stretch toward the ends of the scalar distribution, i.e. from local markets to global legitimacy.

### 5.3. The local scale and its facets

We argue that materialization is key in order to get a grip on the geographical implications of TIS dynamics in space. The geographical context containing these dynamics can be global, according to the global

nature of TISs (Binz and Truffer, 2017). Yet, the field where these dynamics unfold is multiscalar, and their materialization is always local. The local is the scale where investments into installations and buildings create ‘facts on the ground’. Focusing on the local scale in TISs therefore makes it possible to incorporate materialization processes into the study of innovation, which resonates with calls to direct more attention toward the ‘materiality’ of innovations and transitions (Birch and Calvert, 2015; Van Assche et al., 2022). In our study, the coming of TIS-related physical artefacts into existence determined the geographical scope of the local BRTIS. It is for this reason that our definition of the TIS local scale is based not on a pre-defined (sub-regional) unit, such as a city, or municipality, but instead on the outcome of the very materialization process. First, this approach provides a ‘clear starting point’ for the analysis. Second, it provides the most precise geographical delineation of TIS-related processes at any given time, be it a small area occupied by a single sugar refinery, such as at the beginning of the local BRTIS evolution, or roughly 219 ha occupied by its 11 actors at the end. In this sense, our study also follows the calls for a relational approach in the study of scales, where scales are not ‘fixed containers’, but instead are flexible and are defined in relation to each other (Bulkeley, 2005; Moore, 2008).

The geographical distribution of materialization during the evolution of the local BRTIS (Fig. 11) reveals that the local scale contained most of the materialization processes (25 out of 27 instances). Yet, in two instances – in 2008 and 2015 – we observed materialization beyond the local scale. On the one hand, we have argued that materialization is always local and have based our definition of the TIS local scale on this idea. On the other hand, Fig. 11 reveals that not all instances of materialization stemming from the activities at the local BRTIS took place at the local scale, confirming that ‘local’ and ‘materialization’ are not synonymous. The resolution of this conceptual paradox lies in the perspective, from which one might consider the respective TIS. The two instances of materialization at the regional and European scales can be considered local materialization processes if the biorefining TIS is analyzed from the perspective of any of those two local scales, containing the materialized plants. Yet, from the perspective of our case – the local BRTIS – those two instances of materialization occurred at other scales. Note that in our study, we used the parallels between ‘materialization’ and ‘the local’ primarily for the sake of defining the TIS local scale, which, as we have also stated, must be a *contiguous* geographical area. Other ‘noncontiguous’ areas containing processes of materialization do not fall under the definition of the TIS local scale in question.

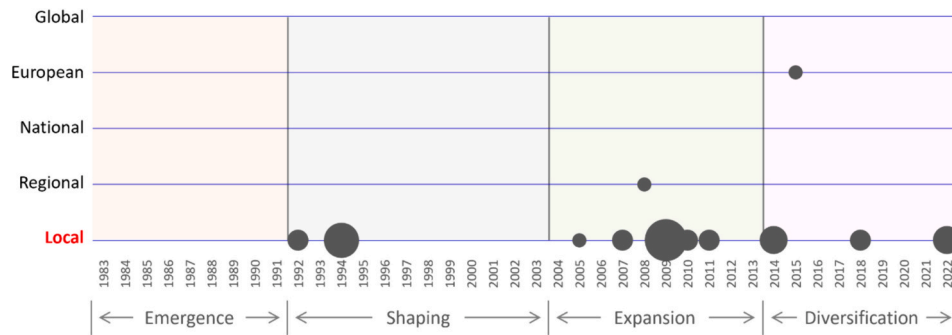


Fig. 11. The geographical distribution of Materialization during the evolution of the local BRTIS.

#### 5.4. Policy implications

Separating the local from the regional scale in TISs can open new avenues for policies aiming to drive technological innovations. Different local scales of TISs can vary in their innovativeness, institutional environment, and degree of market access of end products. Therefore, policies should exploit the specific characteristics of these areas hosting the local scales of the respective TISs, rather than letting a national or regional policy agenda overlooking the local particularities. For instance, motivating businesses to join biorefineries and thus promoting their growth has been a complicated issue (Bauer et al., 2017). In this regard, a clear target for policy is revealed based on our results on the internal market formation. While trying to stimulate firm entry, the policy should promote the formation of internal markets in biorefineries by fostering materialization processes at the local scale. The case of the local BRTIS revealed that the materialization of proximate plants and factories, as well as of pipeline facilities connecting them provided a significant supply of available local by-products both in terms of their quantity and diversity. The opportunities to utilize and benefit from these local markets were the primary motivation for many external actors to join the local BRTIS, especially in the periods of expansion and diversification. Looking to the innovation policy through the prism of technological materialization, beyond more conventional targets such as actors, networks, and institutions, thus opens new locally-tailored policy instruments aimed at increasing the streams of local by-products through fostering materialization processes at the local scale.

Promoting biorefinery-internal markets of by-products through local materialization processes can also support the formation of 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 prerequisite for firms to be able to access markets of bio-based end products. Therefore, biorefinery policies should focus on shaping local existing markets as 'protected spaces' (Bergek et al., 2008c) that firms can rely on to target end markets at broader scales as well. However, such policy measures will have to align with the interests of incumbent actors, who can control the access to natural resources (Hansen and Coenen, 2017; Ayrapetyan et al., 2022). Following their political interests and short-term profit streams (Hansen and Coenen, 2017), incumbents often create strong technological lock-ins around the possible uses of natural resources (Ayrapetyan et al., 2022) and are reluctant to diversify into high value products. Therefore, without relevant demand-side policies, the 'incumbent's curse' (Chandy and Tellis, 2000; Roy and Sarkar, 2016) in biorefinery technology innovations might lead to a trade-off between agro-industrial specialization within a limited varieties of biomass and diversification into high value products.

Policy makers should also use the legitimacy of biorefining technologies as a tool to support local biorefineries. As a basis for attracting different resources (Markard et al., 2016), technology legitimacy can be promoted through international organizations, NGOs, and industry

associations. Involving these organizations in the developments and achievements at the local context might strengthen technology legitimacy as well as foster broader societal acceptance of the consumer products (Wilde and Hermans, 2021). Policy should 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 scales. As illustrated by our results, such broad-scale legitimacy formation might help local actors to expand their access to resources situated at broader scales.

#### 6. Conclusion

This study introduced a new TIS perspective focusing primarily on the local scale which interacts with broader scales through structural couplings. We developed a new way of conceptualizing a specific scale in TISs based on technological materialization and illustrated our perspective with a case study on the evolution of a particular local scale of the biorefining TIS. Adopting the TIS functions approach, we studied the evolution of the local BRTIS by analyzing its local functional dynamics and structural couplings. The results revealed shifting configurations of TIS functions and their interactions at various scales in different periods. While the dynamics at the local scale were characterized mainly by materialization of biorefining technology and local market formation, broader scales played more diverse and flexible roles by providing resources to, forming end markets for, and dissemination the legitimacy of the local BRTIS.

The study contributed to the TIS literature by defining a specific geographical scale in TISs based on the process of technological materialization thus refraining from setting a priori spatial boundaries. In particular, the geographical distribution of market formation processes, characterized both by local markets of by-products and markets of bio-based end products at broader scales, contributed to the literature on 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 scales and its potential to expand the resource access of local actors.

To support the development of biorefineries, policy makers should promote the formation of biorefinery-internal markets through local materialization processes. This can also help to shape markets of advanced bio-based materials and products. Policy makers should also aid the dissemination of narratives of local success stories at broader scales, particularly through transnational organizations, industry associations, and NGOs.

Future studies might consider these factors by studying the biorefining TIS from the perspective of different local scales operating in different contexts in order to find out whether they 'behaved' in a similar or different way. Another aspect that might be included in future studies on local scales of TISs is the positive/negative feedback loops of TIS functions, i.e. 'innovation motors' (Hekkert et al., 2007; Suurs, 2009; Hellmark, 2010). Studies can help in designing spatially-sensitive

policies aiming to reinforce virtuous cycles of TIS functions that shift geographical scales over time.

### Funding

This research was funded by the German Federal Ministry of Education and Research (BMBF) (grant number 031B0020) and by the Chair in Bioeconomy and Sustainable Development (NEOMA Business School, Marne Ardennes Chamber of Commerce, Caisse d'Epargne Grand Est Europe, Greater East Region, Carbone). The funding sources had no role in the design and conduct of the study.

### CRedit authorship contribution statement

**David Ayrapetyan:** Visualization, Writing – original draft, Conceptualization, Formal analysis, Investigation, Methodology. **Nicolas Befort:** Conceptualization, Investigation, Resources, Validation, Writing – review & editing. **Frans Hermans:** Conceptualization, Funding acquisition, Project administration, Supervision, Writing – review & editing.

### Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT 3.5 in

## Appendix A. Summarization of data sources

Source of data	Type of data	Use in the narrative
Academic literature	Doctoral theses by Befort (2016) and Nieddu (1998); master's thesis by Pithan (2013); book by Schieb et al. (2015); Journal articles by Thénot et al. (2018) and Morales (2020).	Historical origins of the local BRTIS evolution, important technological and institutional milestones, strategies of actors, types and dynamics of their internal markets of by-products.
Official reports	Reports by Cristal Union (2020), van Walwijk (2005), and European Commission (2014).	Activities of agricultural cooperative Cristal Union, biofuel legislations and incentives in France, information on bio-surfactant production (Wheatoleo) at the local BRTIS
Websites	Websites reporting national, financial, and industry news: <a href="http://www.finanzen.at">www.finanzen.at</a> , <a href="http://www.lefigaro.fr">www.lefigaro.fr</a> , <a href="http://www.lesechos.fr">www.lesechos.fr</a> , <a href="https://infodujour.fr">https://infodujour.fr</a> , <a href="http://www.enerzine.com">www.enerzine.com</a> , <a href="https://renewable-carbon.eu">https://renewable-carbon.eu</a> , <a href="http://www.argusmedia.com">www.argusmedia.com</a> , <a href="http://www.usinenouvelle.com">www.usinenouvelle.com</a> . Websites of actors of the local BRTIS: <a href="http://www.f-r-d.fr">www.f-r-d.fr</a> , <a href="http://www.global-bioenergies.com">www.global-bioenergies.com</a> , <a href="http://www.a-r-d.fr">www.a-r-d.fr</a> , <a href="http://www.vivescia.com">www.vivescia.com</a> . Websites accessed between January–December 2022.	Information on the activities and achievements of different actors at the local BRTIS mostly during the periods of expansion and diversification.
Professional journals	Articles by Bailey (2022) and Stark (2016).	Information on the role of Global Bioenergies in the local BRTIS in 2016 and 2022.
Participatory observations and meetings with stakeholders	Observation and participation in activities of actors and management bodies at the local BRTIS, as well as meetings with various government actors, investors, and stakeholders (25 meetings, 13 events, 6 research projects, 36 interviews carried out by the second author between 2012 and 2022).	Information on current and future projects, confidential projects, actor strategies, and public support.
Interviews	Nine interviews with: 1. senior researcher of the academic chair of the local BRTIS; 2. project manager of the innovation platform of the local BRTIS; 3. director of the academic chair of the local BRTIS; 4. business development manager of the academic chair at the local BRTIS; 5. senior researcher at the University of Reims; 6. project manager of the innovation platform of the local BRTIS; 7. director of R&D of advanced biofuel development at the local BRTIS; 8. researcher of the academic chair of the local BRTIS; 9. research project manager at the Grand Reims community. Interviews conducted both in-person and online.	Information on the history of the local BRTIS, activities of the actors, their knowledge networks and sources of financing. Major projects carried out between 1983 and 2022. Formal and informal institutional frameworks and regulations regarding the formation of internal markets among the local actors. New governance structure implemented at the local BRTIS in 2021.

## Appendix B. Geographical distribution of TIS functions during the evolution of the local BRTIS

The geographical context of entrepreneurial activities related to the evolution of the local BRTIS are presented in Fig. B1. Most of the functions took place at the local and regional scales. During the emergence period, entrepreneurial activities took place predominantly at the regional scale. Over the next two periods, i.e. shaping and expansion, they shifted mostly to local scale. Finally, in the last period, entrepreneurial activities took place at the local scale only. Therefore, we observe a clear pattern of entrepreneurial activities shifting from the regional to the local scale over time.

order to improve grammar and readability of the Abstract. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Data availability

Supplementary data is attached to this article  
[Supplementary Data From local markets to global legitimacy: A materialization perspective on technological innovation system's dynamic \(Original data\)](#) (Mendeley Data)

### Acknowledgments

Special thanks to the handling editor and the two anonymous reviewers who greatly assisted us in improving the paper.



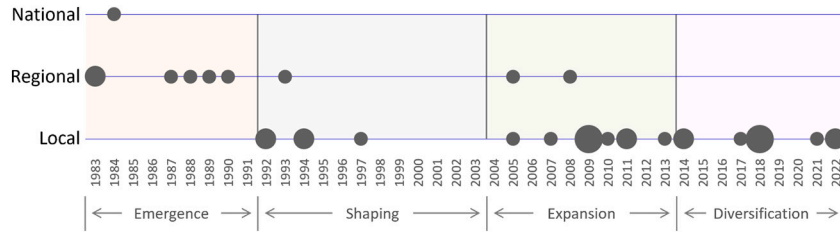


Fig. B1. The geographical distribution of Entrepreneurial Activities during the evolution of the local BRTIS.

We see a slightly different pattern with regard to the geographical context of knowledge development (Fig. B2). In contrast to entrepreneurial activities, the knowledge development processes were distributed more evenly along the local, regional, and national scales. However, this function was still more prevalent at the local scale during the periods of shaping, expansion, and diversification.

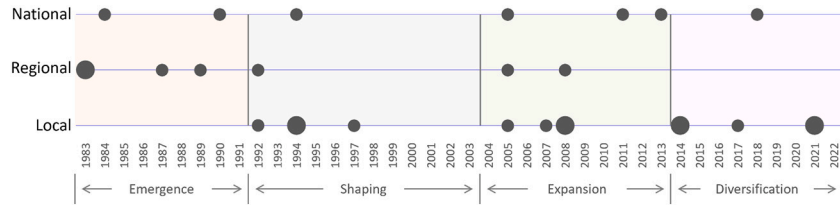


Fig. B2. The geographical distribution of Knowledge Development during the evolution of the local BRTIS.

The function of knowledge diffusion of the local BRTIS had a broader geographical distribution over time compared to the first two functions by taking place at all five geographical scales (Fig. B3). Situated at the regional and national scales in the first period, the processes of knowledge diffusion spread over time to other scales as well. In particular, during the third period knowledge diffusion took place at all five scales – consistent with the geographical ‘expansion’ of the dynamics of the local BRTIS. Finally, during the last period the diffusion of knowledge occurred only at the local and global scales. This function therefore shifted over time toward the both ends of geographical distribution, i.e. local and global.

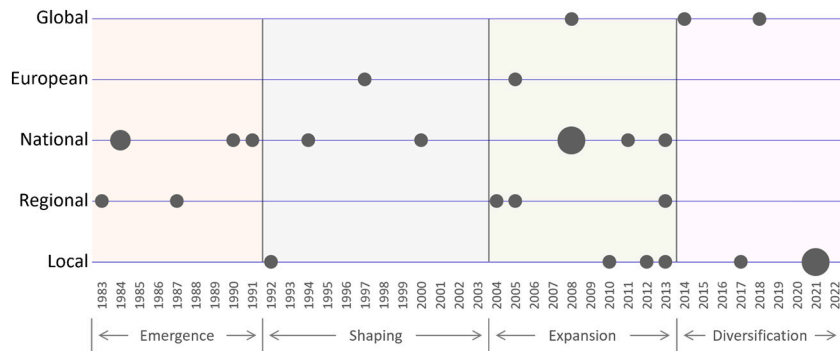


Fig. B3. The geographical distribution of Knowledge Diffusion during the evolution of the local BRTIS.

With regard to guidance of search, we observe a high frequency of corresponding processes, especially at the local, regional, and national scales (Fig. B4). At the local scale, this function was fulfilled with increasing frequency over the four periods, whereas at the regional scale the frequency was decreasing which indicates to a localization of this function over time.

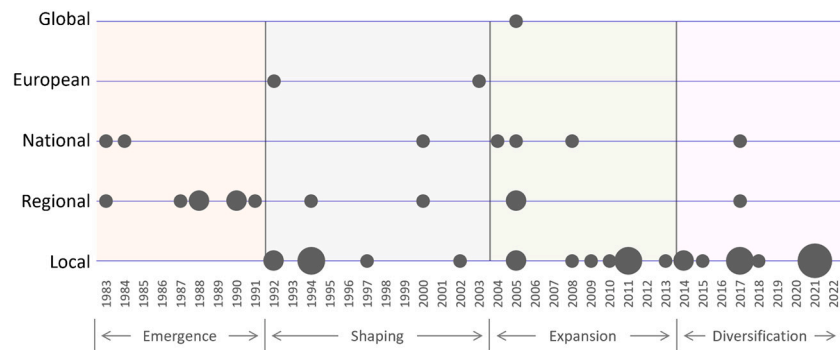


Fig. B4. The geographical distribution of Guidance of Search during the evolution of the local BRTIS.

The geographical distribution of market formation (Fig. B5) is characterized by the prevalence of the corresponding processes at the local, national, and global scales. A specific feature of this distribution is that the market formation at the local scale almost always coincided temporally with market

formation at the national or global scales. This is due to the fact that along with forming national or global markets of end products, the firms at the local BRTIS formed markets of by-products among each other at the local scale.

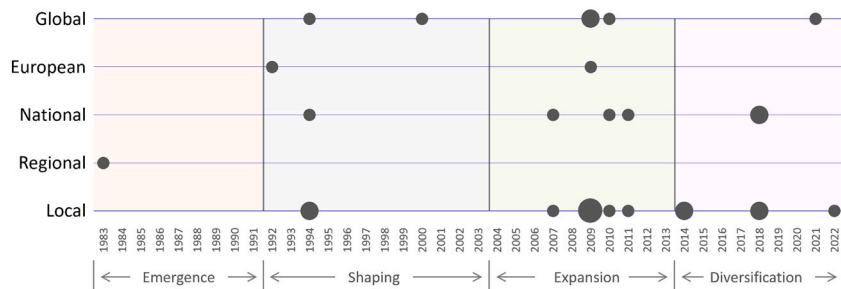


Fig. B5. The geographical distribution of Market Formation during the evolution of the local BRTIS.

With regard to the mobilization of financial, natural, and industrial resources, the geography of these processes involved all the scales except of the global (Fig. B6). There is no significant shift in geographical distribution of this function over time, except of the absence of this function at the local scale in the first period as opposed to the subsequent periods.

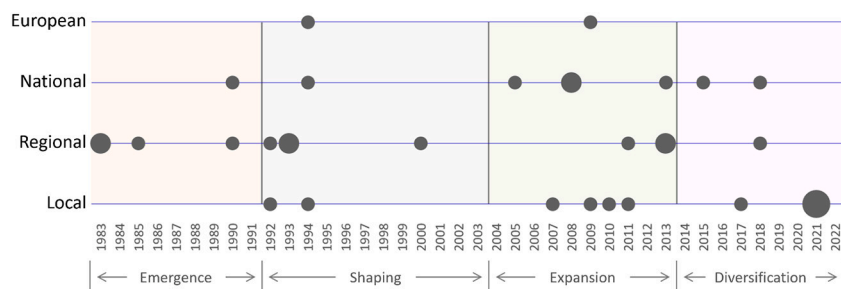


Fig. B6. The geographical distribution of Resource Mobilization during the evolution of the local BRTIS.

The geographical distribution of processes corresponding to creation of legitimacy (Fig. B7) shows that the legitimacy of BRTIS was established first at the regional scale with a shift to higher scales over time. In the last period, actors of the local BRTIS established their legitimacy mostly at the global scale.

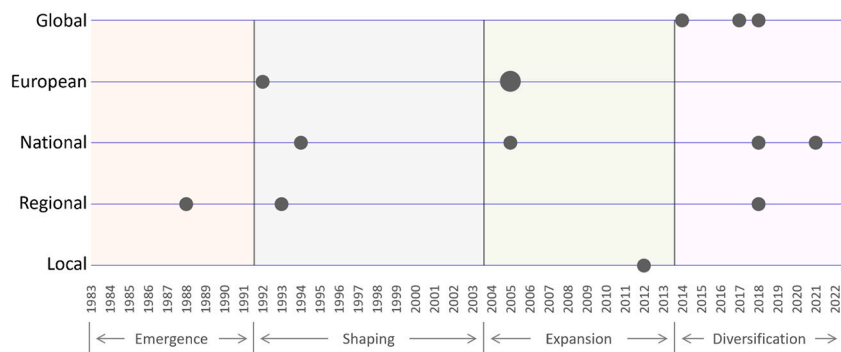


Fig. B7. The geographical distribution of Creation of Legitimacy during the evolution of the local BRTIS.

References

Abbott, A., 1995. Sequence analysis: new methods for old ideas. *Annu. Rev. Sociol.* 93-113. <https://doi.org/10.1146/annurev.so.21.080195.000521>.  
 Allais, F., Lescieux-Katir, H., Chauvet, J.-M., 2021. The continuous evolution of the Bazancourt-Pomacle site rooted in the commitment and vision of pioneering farmers when reality shapes the biorefinery concept. *EFB Bioecon. J.* 100007. <https://doi.org/10.1016/j.bioeco.2021.100007>.  
 Andersson, J., Hellsmark, H., Sandén, B.A., 2018. Shaping factors in the emergence of technological innovations: the case of tidal kite technology. *Technol. Forecast. Soc. Chang.* 132, 191–208. <https://doi.org/10.1016/j.techfore.2018.01.034>.  
 Ayrapetyan, D., 2023. *Technological Innovations and Sustainability Transitions in the Bioeconomy: A Multiscalar Approach Toward the Development of Bioclusters*. Martin-Luther-Universität Halle-Wittenberg, Universitäts- und Landesbibliothek Sachsen-Anhalt, Halle (Saale). <https://doi.org/10.25673/110903>.

Ayrapetyan, D., Hermans, F., 2020. Introducing a multiscalar framework for biocluster research: a meta-analysis. *Sustainability* 12 (9), 3890. <https://doi.org/10.3390/su12093890>.  
 Ayrapetyan, D., Befort, N., Hermans, F., 2022. The role of sustainability in the emergence and evolution of bioeconomy clusters: an application of a multiscalar framework. *J. Clean. Prod.* 376, 134306. <https://doi.org/10.1016/j.jclepro.2022.134306>.  
 Bailey, M., 2022. Global bioenergies starts up production of bio-based isobutene. *Chem. Eng.* <https://www.chemengonline.com/global-bioenergies-starts-up-production-of-bio-based-isobutene/?printmode=1#disqus-anchor>, 2017.  
 Barry, A., 2006. Technological zones. *Eur. J. Soc. Theory* 9 (2), 239–253. <https://doi.org/10.1177/1368431006063343>.  
 Bauer, F., Coenen, L., Hansen, T., McCormick, K., Palgan, Y.V., 2017. Technological innovation systems for biorefineries: a review of the literature. *Biofuels Bioprod. Biorefin.* 11 (3), 534–548. <https://doi.org/10.1002/bbb.1767>.  
 Befort, N., 2016. Pour une mésoéconomie de l'émergence de la bioéconomie: Représentations, patrimoines productifs collectifs et stratégies d'acteurs dans la

- régulation d'une chimie doublement verte. Université de Reims Champagne-Ardenne Reims. <https://doi.org/10.4000/regulation.12121>.
- Bento, N., Fontes, M., 2015. Spatial diffusion and the formation of a technological innovation system in the receiving country: the case of wind energy in Portugal. *Environ. Innov. Soc. Trans.* 15, 158–179. <https://doi.org/10.1016/j.eist.2014.10.003>.
- Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., Rickne, A., 2008a. Analyzing the functional dynamics of technological innovation systems: a scheme of analysis. *Res. Policy* 37 (3), 407–429. <https://doi.org/10.1016/j.respol.2007.12.003>.
- Bergek, A., Jacobsson, S., Hekkert, M., 2008b. Functions in innovation systems: a framework for analysing energy system dynamics and identifying goals for system-building activities by entrepreneurs and policy makers. In: Foxon, T., Köhler, J., Oughton, C. (Eds.), *Innovations for a Low Carbon Economy: Economic, Institutional and Management Approaches*. Edward Elgar, Cheltenham.
- Bergek, A., Jacobsson, S., Sandén, B.A., 2008c. 'Legitimation' and 'development of positive externalities': two key processes in the formation phase of technological innovation systems. *Tech. Anal. Strat. Manag.* 20 (5), 575–592. <https://doi.org/10.1080/09537320802292768>.
- Bergek, A., Hekkert, M., Jacobsson, S., Markard, J., Sandén, B., Truffer, B., 2015. Technological innovation systems in contexts: conceptualizing contextual structures and interaction dynamics. *Environ. Innov. Soc. Trans.* 16, 51–64. <https://doi.org/10.1016/j.eist.2015.07.003>.
- Berkhout, F., Angel, D., Wiecek, A., 2009. Sustainability transitions in developing Asia: are alternative development pathways likely? *Technol. Forecast. Soc. Chang.* 76 (2), 215–217. <https://doi.org/10.1016/j.techfore.2008.04.003>.
- Binz, C., Truffer, B., 2017. Global Innovation Systems—a conceptual framework for innovation dynamics in transnational contexts. *Res. Policy* 46 (7), 1284–1298. <https://doi.org/10.1016/j.respol.2017.05.012>.
- Binz, C., Truffer, B., Li, L., Shi, Y., Lu, Y., 2012. Conceptualizing leapfrogging with spatially coupled innovation systems: the case of onsite wastewater treatment in China. *Technol. Forecast. Soc. Chang.* 79 (1), 155–171. <https://doi.org/10.1016/j.techfore.2011.08.016>.
- Binz, C., Truffer, B., Coenen, L., 2014. Why space matters in technological innovation systems—mapping global knowledge dynamics of membrane bioreactor technology. *Res. Policy* 43 (1), 138–155. <https://doi.org/10.1016/j.respol.2013.07.002>.
- Binz, C., Truffer, B., Coenen, L., 2016. Path creation as a process of resource alignment and anchoring: industry formation for on-site water recycling in Beijing. *Econ. Geogr.* 92 (2), 172–200. <https://doi.org/10.1080/00130095.2015.1103177>.
- Birch, C., Calvert, K., 2015. Rethinking 'drop-in' biofuels: on the political materialities of bioenergy. *Sci. Technol. Stud.* 28 (1), 52–72. <https://doi.org/10.23987/sts.55357>.
- Boon, W.P.C., Edler, J., Robinson, D.K.R., 2020. Market formation in the context of transitions: a comment on the transitions agenda. *Environ. Innov. Soc. Trans.* 34, 346–347. <https://doi.org/10.1016/j.eist.2019.11.006>.
- Bosman, R., Rotmans, J., 2016. Transition governance towards a bioeconomy: a comparison of Finland and The Netherlands. *Sustainability* 8 (10), 1017. <https://doi.org/10.3390/su8101017>.
- Bulkeley, H., 2005. Reconfiguring environmental governance: towards a politics of scales and networks. *Polit. Geogr.* 24 (8), 875–902. <https://doi.org/10.1016/j.polgeo.2005.07.002>.
- Bunnell, T.G., Coe, N.M., 2001. Spaces and scales of innovation. *Prog. Hum. Geogr.* 25 (4), 569–589. <https://doi.org/10.1191/030913201682688940>.
- Carlsson, B., Stankiewicz, R., 1991. On the nature, function and composition of technological systems. *J. Evol. Econ.* 1 (2), 93–118. [https://doi.org/10.1007/978-94-011-0145-5\\_2](https://doi.org/10.1007/978-94-011-0145-5_2).
- Chandy, R.K., Tellis, G.J., 2000. The incumbent's curse? Incumbency, size, and radical product innovation. *J. Mark.* 64 (3), 1–17. <https://doi.org/10.1509/jmkg.64.3.1.18033>.
- Coenen, L., Benneworth, P., Truffer, B., 2012. Toward a spatial perspective on sustainability transitions. *Res. Policy* 41 (6), 968–979. <https://doi.org/10.1016/j.respol.2012.02.014>.
- Cooke, P., Uranga, M.G., Etxebarria, G., 1997. Regional innovation systems: institutional and organisational dimensions. *Res. Policy* 26 (4–5), 475–491. [https://doi.org/10.1016/S0048-7333\(97\)00025-5](https://doi.org/10.1016/S0048-7333(97)00025-5).
- Cristal Union, 2020. Demande d'autorisation d'augmentation de la capacité de traitement de betteraves, d'extension des périmètres d'épandage et d'irrigation.
- De Oliveira, L.G.S., Negro, S.O., 2019. Contextual structures and interaction dynamics in the Brazilian Biogas Innovation System. *Renew. Sust. Energ. Rev.* 107, 462–481. <https://doi.org/10.1016/j.rser.2019.02.030>.
- Deutz, P., Gibbs, D., 2008. Industrial ecology and regional development: eco-industrial development as cluster policy. *Reg. Stud.* 42 (10), 1313–1328. <https://doi.org/10.1080/00343400802195121>.
- Dewald, U., Fromhold-Eisebith, M., 2015. Trajectories of sustainability transitions in scale-transcending innovation systems: the case of photovoltaics. *Environ. Innov. Soc. Trans.* 17, 110–125. <https://doi.org/10.1016/j.eist.2014.12.004>.
- Dewald, U., Truffer, B., 2011. Market formation in technological innovation systems—diffusion of photovoltaic applications in Germany. *Ind. Innov.* 18 (03), 285–300. <https://doi.org/10.1080/13662716.2011.561028>.
- Dewald, U., Truffer, B., 2012. The local sources of market formation: explaining regional growth differentials in German photovoltaic markets. *Eur. Plan. Stud.* 20 (3), 397–420. <https://doi.org/10.1080/09654313.2012.651803>.
- Diakosavvas, D., Frezal, C., 2019. Bio-economy and the sustainability of the agriculture and food system: opportunities and policy challenges. In: *OECD Food, Agriculture and Fisheries Papers*, Vol. No. 136. <https://doi.org/10.1787/d0ad045d-en>. Paris.
- European Commission, 2014. *Where Next for the European Bioeconomy?*
- Frishammar, J., Söderholm, P., Hellsmark, H., Mossberg, J., 2019. A knowledge-based perspective on system weaknesses in technological innovation systems. *Sci. Public Policy* 46 (1), 55–70. <https://doi.org/10.1093/scipol/scy037>.
- Gerring, J., 2016. *Case Study Research: Principles and Practices*. Cambridge university press.
- Gibson, C.C., Ostrom, E., Ahn, T.-K., 2000. The concept of scale and the human dimensions of global change: a survey. *Ecol. Econ.* 32 (2), 217–239. [https://doi.org/10.1016/S0921-8009\(99\)00092-0](https://doi.org/10.1016/S0921-8009(99)00092-0).
- Giurca, A., Späth, P., 2017. A forest-based bioeconomy for Germany? Strengths, weaknesses and policy options for lignocellulosic biorefineries. *J. Clean. Prod.* 153, 51–62. <https://doi.org/10.1016/j.jclepro.2017.03.156>.
- Gosens, J., Lu, Y., Coenen, L., 2015. The role of transnational dimensions in emerging economy 'Technological Innovation Systems' for clean-tech. *J. Clean. Prod.* 86, 378–388. <https://doi.org/10.1016/j.jclepro.2014.08.029>.
- Grouiez, P., Debref, R., Vivien, F.-D., Befort, N., 2023. The complex relationships between non-food agriculture and the sustainable bioeconomy: the French case. *Ecol. Econ.* 214, 107974.
- Gustafsson, J., 2017. Single case studies vs. multiple case studies: a comparative study. Retrieved from. <https://www.diva-portal.org/smash/get/diva2:1064378/FULLTEXT01.pdf>.
- Hansen, T., Coenen, L., 2017. Unpacking resource mobilisation by incumbents for biorefineries: the role of micro-level factors for technological innovation system weaknesses. *Tech. Anal. Strat. Manag.* 29 (5), 500–513. <https://doi.org/10.1080/09537325.2016.1249838>.
- Hansmeier, H., Kroll, H., 2024. The geography of eco-innovations and sustainability transitions: a systematic comparison. In: *ZFW—Advances in Economic Geography*, 0.
- Heiberger, J., Binz, C., Truffer, B., 2020. The geography of technology legitimation: how multiscale institutional dynamics matter for path creation in emerging industries. *Econ. Geogr.* 96 (5), 470–498. <https://doi.org/10.1080/00130095.2020.1842189>.
- Hekkert, M.P., Suurs, R.A., Negro, S.O., Kuhlmann, S., Smits, R.E., 2007. Functions of innovation systems: a new approach for analysing technological change. *Technol. Forecast. Soc. Chang.* 74 (4), 413–432. <https://doi.org/10.1016/j.techfore.2006.03.002>.
- Hellsmark, H., 2010. *Unfolding the Formative Phase of Gasified Biomass in the European Union: The Role of System Builders in Realising the Potential of Second-generation Transportation Fuels From Biomass*. Chalmers Tekniska Hogskola, Sweden.
- Hellsmark, H., Mossberg, J., Söderholm, P., Frishammar, J., 2016. Innovation system strengths and weaknesses in progressing sustainable technology: the case of Swedish biorefinery development. *J. Clean. Prod.* 131, 702–715. <https://doi.org/10.1016/j.jclepro.2016.04.109>.
- Hermans, F., 2021. Bioclusters and sustainable regional development. In: *Rethinking Clusters*. Springer, pp. 81–91. [https://doi.org/10.1007/978-3-030-61923-7\\_6](https://doi.org/10.1007/978-3-030-61923-7_6).
- Hermans, F., Geerling-Eiff, F., Potters, J., Klerkx, L., 2019. Public-private partnerships as systemic agricultural innovation policy instruments—assessing their contribution to innovation system function dynamics. *NJAS-Wageningen J. Life Sci.* 88, 76–95. <https://doi.org/10.1016/j.njas.2018.10.001>.
- Hojckova, K., Ahlborg, H., Morrison, G.M., Sandén, B., 2020. Entrepreneurial use of context for technological system creation and expansion: the case of blockchain-based peer-to-peer electricity trading. *Res. Policy* 49 (8), 104046. <https://doi.org/10.1016/j.respol.2020.104046>.
- Jacobsson, S., Bergek, A., 2011. Innovation system analyses and sustainability transitions: contributions and suggestions for research. *Environ. Innov. Soc. Trans.* 1 (1), 41–57. <https://doi.org/10.1016/j.eist.2011.04.006>.
- Lazarevic, D., Kautto, P., Antikainen, R., 2020. Finland's wood-frame multi-storey construction innovation system: analysing motors of creative destruction. *Forest Policy Econ.* 110, 101861. <https://doi.org/10.1016/j.forpol.2019.01.006>.
- Lukkarinen, J., Berg, A., Salo, M., Tainio, P., Alhola, K., Antikainen, R., 2018. An intermediary approach to technological innovation systems (TIS)—the case of the cleantech sector in Finland. *Environ. Innov. Soc. Trans.* 26, 136–146. <https://doi.org/10.1016/j.eist.2017.04.003>.
- Lundvall, B.-Å., 1988. *Innovation as an Interactive Process: From User-producer Interaction to the National System of Innovation*. Pinter, London.
- Malerba, F., 2002. Sectoral systems of innovation and production. *Res. Policy* 31 (2), 247–264. [https://doi.org/10.1016/S0048-7333\(01\)00139-1](https://doi.org/10.1016/S0048-7333(01)00139-1).
- Markard, J., Raven, R., Truffer, B., 2012. Sustainability transitions: an emerging field of research and its prospects. *Res. Policy* 41 (6), 955–967. <https://doi.org/10.1016/j.respol.2012.02.013>.
- Markard, J., Hekkert, M., Jacobsson, S., 2015. The technological innovation systems framework: response to six criticisms. *Environ. Innov. Soc. Trans.* 16, 76–86. <https://doi.org/10.1016/j.eist.2015.07.006>.
- Markard, J., Wirth, S., Truffer, B., 2016. Institutional dynamics and technology legitimacy—a framework and a case study on biogas technology. *Res. Policy* 45 (1), 330–344. <https://doi.org/10.1016/j.respol.2015.10.009>.
- Marston, S.A., 2000. The social construction of scale. *Prog. Hum. Geogr.* 24 (2), 219–242. <https://doi.org/10.1191/03091320067408627>.
- Miörner, J., Binz, C., 2021. Towards a multi-scalar perspective on transition trajectories. *Environ. Innov. Soc. Trans.* 40, 172–188. <https://doi.org/10.1016/j.eist.2021.06.004>.
- Moore, A., 2008. Rethinking scale as a geographical category: from analysis to practice. *Prog. Hum. Geogr.* 32 (2), 203–225. <https://doi.org/10.1177/0309132507087647>.
- Morales, M.E., 2020. *Industrial Symbiosis, a Circular Bioeconomy Strategy. The Sugar Beet Case Study at the Bazancourt-Pomacle Platform*. Editions Oeconomia.
- Mousavi, S., Hellsmark, H., Söderholm, P., 2023. How can pilot and demonstration plants drive market formation? Lessons from advanced biofuel development in Europe. *Technol. Forecast. Soc. Chang.* 194, 122703. <https://doi.org/10.1016/j.techfore.2023.122703>.

- Musioliak, J., Markard, J., Hekkert, M., Furrer, B., 2020. Creating innovation systems: how resource constellations affect the strategies of system builders. *Technol. Forecast. Soc. Chang.* 153, 119209. <https://doi.org/10.1016/j.techfore.2018.02.002>.
- Negro, S.O., Hekkert, M.P., Smits, R.E., 2007. Explaining the failure of the Dutch innovation system for biomass digestion—a functional analysis. *Energy Policy* 35 (2), 925–938. <https://doi.org/10.1016/j.enpol.2006.01.027>.
- Nevezorova, T., 2022. Functional analysis of technological innovation system with inclusion of sectoral and spatial perspectives: the case of the biogas industry in Russia. *Environ. Innov. Soc. Trans.* 42, 232–250. <https://doi.org/10.1016/j.eist.2022.01.005>.
- Nieddu, M., 1998. *Dynamiques de longue période dans l'agriculture productiviste et mutations du système agro-industriel français contemporain*. Université de Reims Champagne Ardenne, Reims.
- OECD, 2017. *Biorefineries models and policy* [press release]. Retrieved from. [https://one.oecd.org/document/DSTI/STP/BNCT\(2016\)16/REV1/en/pdf](https://one.oecd.org/document/DSTI/STP/BNCT(2016)16/REV1/en/pdf).
- Pentland, B.T., 1999. Building process theory with narrative: from description to explanation. *Acad. Manag. Rev.* 24 (4), 711–724. <https://doi.org/10.5465/amr.1999.2553249>.
- Philp, J., Winickoff, D., 2017. Clusters in industrial biotechnology and bioeconomy: the roles of the public sector. *Trends Biotechnol.* 35 (8), 682–686. <https://doi.org/10.1016/j.tibtech.2017.04.004>.
- Philp, J., Winickoff, D., 2019. Innovation ecosystems in the bioeconomy. In: *OECD Science, Technology and Industry Policy Papers*. OECD Publishing, Paris. <https://doi.org/10.1787/e2e3d8a1-en>.
- Piore, M.J., 2006. Qualitative research: does it fit in economics? 1. *Eur. Manag. Rev.* 3 (1), 17–23. <https://doi.org/10.1057/palgrave.emr.1500053>.
- Pithan, F., 2013. *Développement d'une méthodologie pour l'analyse d'un écosystème socioéconomique émergent et le management d'un projet complexe d'innovation – Application au projet PIVERT*. University of Technology of Compiègne.
- Poole, M.S., Van de Ven, A.H., Dooley, K., Holmes, M.E., 2000. *Organizational Change and Innovation Processes: Theory and Methods for Research*. Oxford University Press.
- Raven, R., Schot, J., Berkhout, F., 2012. Space and scale in socio-technical transitions. *Environ. Innov. Soc. Trans.* 4, 63–78. <https://doi.org/10.1016/j.eist.2012.08.001>.
- Reichardt, K., Negro, S.O., Rogge, K.S., Hekkert, M.P., 2016. Analyzing interdependencies between policy mixes and technological innovation systems: the case of offshore wind in Germany. *Technol. Forecast. Soc. Chang.* 106, 11–21. <https://doi.org/10.1016/j.techfore.2016.01.029>.
- Rohe, S., 2020. The regional facet of a global innovation system: exploring the spatiality of resource formation in the value chain for onshore wind energy. *Environ. Innov. Soc. Trans.* 36, 331–344. <https://doi.org/10.1016/j.eist.2020.02.002>.
- Rohe, S., Chlebna, C., 2021. A spatial perspective on the legitimacy of a technological innovation system: regional differences in onshore wind energy. *Energy Policy* 151, 112193. <https://doi.org/10.1016/j.enpol.2021.112193>.
- Rohe, S., Mattes, J., 2022. What about the regional level? Regional configurations of Technological Innovation Systems. *Geoforum* 129, 60–73. <https://doi.org/10.1016/j.geoforum.2022.01.007>.
- Roy, R., Sarkar, M., 2016. Knowledge, firm boundaries, and innovation: mitigating the incumbent's curse during radical technological change. *Strateg. Manag. J.* 37 (5), 835–854. <https://doi.org/10.1002/smj.2357>.
- Schieb, P.-A., Lescieux-Katir, H., Thénot, M., Clément-Larosière, B., 2015. *Biorefinery 2030*. In: *Future Prospects for the Bioeconomy*. Springer.
- Stark, A., 2016. *Global Bioenergies Produces Highly Purified Isobutene*. Process Worldwide.
- Steen, M., Andersen, A.D., Finstad, J., Jordal, K., Hansen, T., Hanson, J., Skjølvold, T.M., 2022. A socio-technical perspective on CCS innovation system dynamics in Norway. In: *Proceedings of the 16th Greenhouse Gas Control Technologies Conference (GHGT-16)* 23-24 Oct 2022.
- Stuart, P.R., El-Halwagi, M.M., 2012. *Integrated Biorefineries: Design, Analysis, and Optimization*. CRC press.
- Suurs, R.A., 2009. *Motors of Sustainable Innovation: Towards a Theory on the Dynamics of Technological Innovation Systems*. Utrecht University.
- Suurs, R.A., Hekkert, M.P., 2009. Cumulative causation in the formation of a technological innovation system: the case of biofuels in the Netherlands. *Technol. Forecast. Soc. Chang.* 76 (8), 1003–1020. <https://doi.org/10.1016/j.techfore.2009.03.002>.
- Swyngedouw, E., 2004. Globalisation or 'glocalisation'? Networks, territories and rescaling. *Camb. Rev. Int. Aff.* 17 (1), 25–48. <https://doi.org/10.1080/0955757042000203632>.
- Thénot, M., Bouteiller, C., Lescieux-Katir, H., 2018. *Agricultural Cooperatives as Agents of Industrial Symbiosis*, 1. *RECMA*, pp. 31–47.
- Tsvetanova, L., Carraresi, L., Wustmans, M., Bröring, S., 2022. Actors' strategic goals in emerging technological innovation systems: evidence from the biorefinery sector in Germany. *Tech. Anal. Strat. Manag.* 34 (7), 760–773. <https://doi.org/10.1080/09537325.2021.1919300>.
- Van Alphen, K., Van Ruijven, J., Kasa, S., Hekkert, M., Turkenburg, W., 2009. The performance of the Norwegian carbon dioxide, capture and storage innovation system. *Energy Policy* 37 (1), 43–55. <https://doi.org/10.1016/j.enpol.2008.07.029>.
- Van Assche, K., Duineveld, M., Beunen, R., Valentinov, V., Gruezmacher, M., 2022. Material dependencies: hidden underpinnings of sustainability transitions. *J. Environ. Policy Plan.* 24 (3), 281–296. <https://doi.org/10.1080/1523908x.2022.2049715>.
- Van de Ven, A., Poole, M., 2005. Alternative approaches for studying organizational change. *Organ. Stud.* 26 (9), 1377–1404. <https://doi.org/10.1177/0170840605056907>.
- van Walwijk, M., 2005. *Biofuels in France 1990–2005*.
- Vivien, F.D., Nieddu, M., Befort, N., Debref, R., Giampietro, M., 2019. The hijacking of the bioeconomy. *Ecol. Econ.* 159, 189–197. <https://doi.org/10.1016/j.ecolecon.2019.01.027>.
- Walrave, B., Raven, R., 2016. Modelling the dynamics of technological innovation systems. *Res. Policy* 45 (9), 1833–1844. <https://doi.org/10.1016/j.respol.2016.05.011>.
- Wieczorek, A.J., Hekkert, M.P., Coenen, L., Harmsen, R., 2015. Broadening the national focus in technological innovation system analysis: the case of offshore wind. *Environ. Innov. Soc. Trans.* 14, 128–148. <https://doi.org/10.1016/j.eist.2014.09.001>.
- Wilde, K., Hermans, F., 2021. Deconstructing the attractiveness of biocluster imaginaries. *J. Environ. Policy Plan.* 23 (2), 227–242. <https://doi.org/10.1080/1523908x.2021.1891872>.
- Winter, S.G., Nelson, R.R., 1982. *An Evolutionary Theory of Economic Change*. University of Illinois at Urbana-Champaign's Academy for Entrepreneurial Leadership Historical Research Reference in Entrepreneurship.
- Yin, R.K., 2018. *Case Study Research and Applications: Design and Methods*. Sage Publications.
- Yuan, X., Li, X., 2021. Mapping the technology diffusion of battery electric vehicle based on patent analysis: a perspective of global innovation systems. *Energy* 222, 119897. <https://doi.org/10.1016/j.energy.2021.119897>.