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Sustainability Transitions:
the role of space and policy

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Declaration of Authorship

I, Almona Tani, declare that this thesis titled “Sustainability Transitions: the role of space and policy” and the chapters presented in it are written by me. I confirm that where I have quoted or consulted the work of others, the source has always been given, and I declare that all elaborations on the data are my responsibility.

The work presented in this thesis are done wholly or mainly while in candidature for a PhD degree at this University.

The research in Chapter 2 is in collaboration with Piergiuseppe Morone (Unitelma-Sapienza Università di Roma) and part of the data used for the research were collected during a visiting period at Northeastern University in Boston (MA, USA) financed by a Marie Sklodowska-Curie fellowship within the EU Agenda Horizon 2020 Research Project MAPS-LED (Multidisciplinary Approach to Plan Specialization for Local Economic Development).

The project in Chapter 3 has been developed in collaboration with Antonio Lopolito (University of Foggia) and Piergiuseppe Morone (Unitelma-Sapienza Università di Roma).

The research in Chapter 4 is part of a joint project with Enrica Imbert (Unitelma-Sapienza Università di Roma), Luana Ladu (Technische Universitaet Berlin), and Piergiuseppe Morone (Unitelma-Sapienza Università di Roma) and part of the data used for the research were collected during a visiting period at Technische Universitaet Berlin financed by the mobility scholarship of Sapienza University of Rome.

Contents

Declaration of Authorship **1**

1. Introducing sustainability transitions: the case of bio-based economy **7**
1.1. MLP as a useful framework for transition studies 8
1.2. Transition dynamics 10
1.3. The transition to a bio-based economy 12
1.3.1. Transition challenges and need for policy strategy 13
1.3.1.1. National, regional, industrial, and social strategies 13
1.3.1.2. Strategic Niche Management in the bio-based economy niches 14
1.3.1.3. Society in the bio-based economy system 15
1.3.2. Criticisms on sustainability 15
1.4. Aim and structure of the thesis 16

2. Patterns of clean energy transition in the Boston area **19**
2.1. The multi-levels of clean energy technologies: identifying niches, regimes and landscapes in the Boston area 20
2.1.1. The landscape 21
2.1.2. The regime 22
2.1.3. The clean energy niches 23
2.2. Qualitative Discourse Analysis Method 24
2.4. Storylines of transition to clean energy technologies in the Boston Area 27
2.4.1. The dominant storyline 27
2.4.2. Legitimizing and delegitimizing incumbent regime 29
2.5. Discussion and concluding remarks 33

3. Spatial perspectives on niche empowerment: an agent based model **35**
3.1. Geographical dimension in transition studies 35
3.1.1. Strategic Niche Management in sustainability transition 36
3.1.2. Spatial aspects in innovative production systems 37
3.1.3. The suitability of agent-based models 37
3.2. The Agent-Based Model 38
3.2.1. Framing environment characteristics 38
3.2.2. Knowledge and power 39
3.2.3. *Networking 40*
3.2.4. *Expectations 42*
3.2.5. *Behavioural rules and firms' decision processes 43*
3.3. Policy tool and simulation results 44
3.4. Conclusions 47

4. The transition towards a bio-based economy: a comparative social network analysis **49**
4.1. Theoretical framework 50
4.2. Empirical Strategy and Methodology 51
4.3. Case studies and results 52
4.3.1. Convergence of expectations 52
4.3.2. Learning processes 54
4.3.2.1. Informal knowledge share 54
4.3.2.2. Formal knowledge exchange 55
4.3.3. Networking with powerful actors 56
4.4. Discussion and Conclusions 58

Key Findings and Conclusions **60**

Bibliography **62**

List of Figures

2.1 The Boston area 22
2.2 Core and Periphery actors 25

3.1 Agents switching to the niche technology in a local niche and in a global niche (low level of knowledge) 44
3.2 Number of links created in a local niche and in a global niche (low level of knowledge) 45
3.3 Agents switching to the niche technology and number of links created in the global-local niche (low level of knowledge) 46
3.4 Agents switching to the niche technology in a local niche and in a global niche (high level of knowledge) 46
3.5 Agents switching to the niche technology and number of links created in the global-local niche (high level of knowledge) 47

4.1 Firms' expectations on the future of the bioplastics sector 53
4.2 Firms' perception on exiting challenges to the future of the bioplastics sector 54
4.3 Informal knowledge network in the Italian bioplastics industry and the German bioplastics industry 55
4.4 Formal knowledge network in the Italian bioplastics industry and the German bioplastics industry 56
4.5 Powerful actors in the informal knowledge network in the Italian bioplastics industry and the German bioplastics industry 57
4.6 Powerful actors in the formal knowledge network in the Italian bioplastics industry and the German bioplastics industry 58

List of Tables

2.1 MassCEC Grant Programmes 24
2.2 List of key actors' organisations 26
2.3 Overview of dominant storyline [*S1*] 29
2.4 Framing the conflict between storylines [*S2*] and [*S3*] 33

3.1 Parameters summary 43

4.1 Measures of the informal knowledge network 55
4.2 Measures of the formal knowledge network 56

Chapter 1

Introducing sustainability transitions: the case of bio-based economy

When Malthus published *An essay of the principle of the population as it affects the future improvement of society* in 1798 he was announcing a problem of natural resources availability which was yet to come. This theory, though being radical and innovative, didn't consider technological development which has been able for decades to generate economic growth in a context of demographic expansion (Wilson and Dragusanu, 2008; Kharas, 2010; Pezzini, 2012; UN, 2015). Notwithstanding, the production system based on a linear model and on fossil fuel resources coupled with an increasing consumption generated by population growth, have overstretched the pressure on environment. To "unlock" the current carbon lock-in and dismantle the linearity of production, purchase, consumption, and waste, the challenge remains the provision of human well-being and maintain an increasing trend of economic growth by valorising natural and renewable resources.

Whereas society, economy, and environment are not separate systems but complementary elements of the same system, the focus of analysis cannot only be on the production and supply side of new technologies: it stands also on the fulfilment of social functions and environmental sustainability. The coevolution of technological innovation, together with its diffusion mechanisms, its impact on and its benefit from the society, are important topics of analysis that have been identified in the literature with the concept of socio-technical systems (Geels, 2004; Geels and Kemp, 2007; Geels and Schot, 2007, Markard and Truffer, 2008). A socio-technical system consists of technological inputs, infrastructures, markets, regulation, policies, institutions, and networks, forming a stable configuration (a dominant regime) able to resist to some degree of pressure coming from various sources acting from outside and inside the system.

Therefore, the development of new radical innovations to address one element of the system is a necessary but not sufficient condition to destabilise the regime; rather a dynamic transformation of the socio-technical system is needed to successfully challenge the dominant regime. As pointed out by several scholars (Rockström et al., 2009; Rashid et al., 2013; Robért et al., 2013; Broman et al., 2017; Broman and Robért, 2017; Korhonen et al., 2017; D'Amato et al., 2017; EC, 2014; CIRAIG, 2015; The Fourth BioEconomy Stakeholders' Conference, 2016) a systemic transition toward a circular economy can be a solution to reduce the burden of growing population and people needs, over global natural resource. Such transition would entail progressively moving towards a model where: (1) natural and renewable resources (biomasses) take over fossil based resources; (2) production focuses on recovery of inputs along the whole value chain (this including re-engineering efforts to produce goods whose materials can effectively be reused and recycled once products end-of-life is reached); (3) consumption aims at reducing, reusing, and sharing goods over owning them.

Encouraging signals are pointing at this direction. For instance, there is: an increase in R&D efforts to develop clean technologies, able to reduce emissions and save resources (Del Rìo Gonzales, 2005; Frondel et al., 2007; Carley, 2011); a promising uptake of bio-based economy achieved with products made from renewable materials (Langeveld et al., 2010; Schmid et al., 2012; Vanholme et al., 2013; Pfau et al., 2014); a rapid growth of sharing practices in consumption affecting many sectors (travelling, dressing, holidays, and feeding) (Heinrichs, 2013; Martin, 2016; Schor, 2016; Frenken, 2017). These examples are all pieces of a jigsaw puzzle showing a common trajectory of change – a transition towards a radically new socio-technological model – not exempt from challenges, concerns, and criticisms.

The goal of this chapter is to provide a framework of the sustainability transitions literature adopted in this thesis, highlighting and introducing the main topics discussed in the further chapters.

The remainder of the chapter is structured as follows. Section 1.1 provides an in-depth analysis of the Multi-Level Perspective and its divergence with other theoretical frameworks of technological innovation. Section 1.2 focuses on transition dynamics passing through the diffusion of clean technologies. Section 1.3 discusses the bio-based economy as a systemic transition within the MLP, paying particular attention to challenges and criticisms. Finally, in section 1.4 aim and structure of the thesis are defined.

1.1. MLP as a useful framework for transition studies

The technological evolution of the last three decades has triggered a flourishing debate on the one hand on the factors of technological development, deployment, and diffusion, and on the other hand on its dimension of analysis moving the focus from market failure to system failure. The concept of system is crucial for explaining the causality and co-development of new technologies with new markets and new social structures, thus new actors and institutional assets, since innovation process is complex (Markard and Truffer, 2008).

For this, innovation systems have been a helpful approach to analyse the dynamics and patterns of technological innovations. Scholars have defined different levels of innovation systems – local, regional, national, sectoral (Breschi and Malerba, 1997; Malerba, 2002), and technological (Carlsson and Stankiewicz, 1991; Bergek et al., 2008) – to theorize the creation and diffusion of radical innovations and their success and failure in different economies (Smith et al., 2010). However, innovation systems focus more on the functioning of systems and the emergence of new systems (Geels, 2004); in this way, they lack a broader perspective of transition from one system to another through substitution of technologies and transformation of sectorial structures (Geels, 2004; Markard and Truffer, 2008). Another criticism moved by various scholars (Geels, 2004; Smith et al., 2010) concerning innovation systems deals with the narrowed definition given to the selection environment that is supposed to include socio-economic factors of technology diffusion. However, this definition does not directly and clearly refer to the demand-side and the fulfilment of societal functions as drivers of technological innovation processes.

In view of the fact that innovation processes require a renewal of physical infrastructures, as well as changes in institutions, culture, and socio-economic interests, the focus has shifted from innovation systems to *system innovation* (Smith et al., 2010; Calvert et al., 2017). Accordingly, the concept of socio-technical system (Geels, 2002; 2004; 2005) has been developed in order to highlight the co-development of technology and society, and to focus the analysis not only on production but also on consumption based on the fulfilment of societal functions. Although the industry-side of innovative technology production is very important, other actors as well are relevant in the innovation process, such as users and consumers, associations, research institutes, and policy-makers. The idea behind socio-technical systems is the existence of networks between and among those actors creating autonomous but interrelated groups that interact in accordance with a deep structure of rules. In fact, for analytical reasons Geels (2004) distinguishes three relatively autonomous and interdependent groups named socio-technical systems, social organisations, and institutions. Since rules are stable and actors and organisations are embedded in structured networks, the MLP has been introduced to understand how radical innovations emerge in a context of aligned groups, generating system innovation and socio-technical transition of the systems (Schot et al., 1994; Rip and Kemp, 1998; Kemp et al., 2001; Geels, 2002; Elzen et al., 2004; Geels and Kemp, 2007).

According to the Multi-Level Perspective (MLP), a socio-technical system is composed of three interconnected levels – niche, regime, and landscape – that apply pressure and are influenced by the developments at each level.

The regime, which is at the core of a socio-technical system, consists of technological artefacts, infrastructures, and knowledge, as well as social actors and networks, which are embedded in an institutional context and behave according to a shared set of rules (Truffer et al., 2002; Geels, 2002; Smith et al., 2005; Raven, 2007). The socio-technical regime represents an incumbent, stable, and resistant socio-technical structure composed of *"… manufacturing corporations, public and private utilities, industrial and government research laboratories, investment and banking houses, sections of technical and industrial societies, departments in educational institutions and regulatory bodies …"* (Hughes, 1987, pp. 76-77), which has various interests for strengthening the regime and contribute to its stability. This approach leads supply-side actors to follow familiar routines, innovating along already known technological trajectories (Dosi, 1982), hence increasing the knowledge on incumbent technologies, decreasing market costs, and strengthening regulation (Smith and Raven, 2012). The notion of path-dependency affects the social component of the regime as well, which is composed of large and stable communities who share common rules to coordinate and consume familiar products because of cultural inertia.

Since actors contribute to the creation of a set of rules, they can also create space for divergent actions because the perception on preferences, resources, socio-economic contexts, and personal objectives is different for any social group (Geels, 2004). Moments of discordance may emerge when the rules do not fit everyone and as a result, radical innovations occur in niches that start to put pressure on the rules for change. Niches, which in the MLP are the micro-level of a socio-technical system, are characterized by an intensive activity of research and trial-and-error experiments. Indeed, they are theorized as "protected spaces" (Smith and Raven, 2007) since the performance of the innovative technology at this stage is not able to deal with the incumbent technologies that overcome the market. According to Geels and Schot (2007) niches and regimes are similar in elements they are composed of, but differ in terms of characteristics of elements. For instance, both niche and regime are organized in socio-economic groups, however, differently from the regime, in the niche these groups are smaller and unstable. Rules as well are an element that characterizes both levels, but in the niche rules are unstable and not well-articulated since they are "in the making" (Geels and Schot, 2007). The evolution path of the niche toward stable socio-economic groups and well-structured rules, determines its development and its relationship with the incumbent regime (Markard and Truffer, 2008; Smith and Raven, 2012). In the next section, we will analyse the niche maturity process and its transition in more detail.

A third level of a socio-technical system according to the MLP refers to the landscape level that represents an external context of influence for both the regime and the niche. The landscape is composed of a *"... set of heterogeneous factors, such as oil prices, economic growth, wars, emigration, broad political coalitions, cultural and normative values, environmental problems."* (Geels, 2002, pp.

1260). This macro-level shapes the transition process through tensions at the regime level and generating mis-alignment and instability in the socio-technical system. Although the landscape level is linked to niche and regime, and can affect the innovation process, it is not *"… influenced by the outcome of innovation processes on a short and mid-term basis."* (Markard and Truffer, 2008, pp. 606) because it is characterized by a deep structure that refers to the material aspects of society that change very slowly (Geels, 2005).

With these three interconnected levels the MLP aims to highlight the inclusion of social groups in the innovation process, as well as to provide a framework of transition dynamics of systems.

1.2. Transition dynamics

As an answer to socio-political concerns about environmental issues, the incumbent socio-technical regime behaves as a selection environment characterized by lock-in and path dependency, thus fed by incremental innovations at most (Geels, 2005). Whereas the niche is where radical innovations, that might significantly reduce environmental impact, are developed (Geels, 2005). The transition from traditional to innovative clean technologies requires both sufficient pressure exerted from the landscape on the regime to open a "window of opportunity", and a mature niche that is able to break through the incumbent regime, jumping through the window of opportunity and establishing itself as a new sustainably innovative regime. So, how does a niche become mature?

According to the literature on Strategic Niche Management (SNM) (Hoogma, 2000; Kemp et al., 2001; Truffer et al., 2002), which provides an evolutionary framework to the niche development process, three internal mechanisms are identified that make the niche more stable and able to switch to innovative technologies.

The first mechanism concerns the learning process that affects the production and accumulation of knowledge by the niche actors. On the one hand, for private firms that may not have technological competencies and financial capacities, acquiring knowledge on new technologies is essential. On the other hand, knowledgeable society on quality and performance of innovative products can accept easily sustainable innovations for the fulfilment of their needs. Innovative performance of an economy is not generated only by direct public and private R&D investments, but is also affected by learning processes and knowledge sharing among research institutions, universities, private firms and organizations with the help of public institutions and intervention (Lundvall, 1992; Nelson, 1993; David and Foray, 1995; Debackere and Veugelers, 2005). Notwithstanding, the research needed for the development of clean technologies is characterized by long time-frames, high costs and uncertainty; these factors discourage private firms' own R&D investments, making formal and informal learning highly relevant and largely based on technology transfer. The latter, defined as the transferability of technical know-how among organizations (Bozeman, 2000), has two implications for the context. On the one hand, due to long-term and risky research, public funding and regulation are needed to foster and increase public and private marketable research (Cantner *et al*., 2016). On the other hand, technology transfer is grounded on a close collaboration between actors and therefore an intense activity of networking; this leads us to the second internal mechanism for niche development.

The building of a social network is a long process, although crucial for obtaining the essential resources required for the transition to innovative technologies (Smith et al., 2005; Lopolito et al., 2011). The network is small and fragile in the initial stage; afterwards it expands and involves new and powerful actors who bring strategic resources and help in the definition of a plan for the niche development. For the accomplishment of a stable network, all the actors should share converging expectations, which is the third internal mechanism.

Converging expectations are significant in order to bring actors together and generate a common purpose, which is lacking in the initial stage of the niche development. A matter of success for researchers and scientists, who are the main actors for the invention and development of innovative technologies, is the deployment and diffusion of these technologies in wider markets. If there is a shared belief that the technology works, it is easier to attract financial resources for research and political support for infrastructural, institutional, and regulatory change (Nissila *et al*., 2014).

Initially, place-specificity factors, e.g. innovative capacity, knowledge, local networking, etc., are crucial for the emergency of the niche (Hansen and Coenen, 2015). However, the process of convergence of expectations, different from the other two mechanisms, is mainly influenced by external pressures and circumstances originated by the landscape, by problems at the regime level, or by technological breakthroughs in other niches (Hoogma, 2000; Lopolito *et al*., 2013). The dynamic process that brings a niche from the early phases of development to maturity (Lopolito *et al*., 2011) is largely conditioned by the empowerment of path-breaking innovations (Smith and Raven, 2012), which transform the niche from a protective space to a competitive space for sustainable innovation.

Smith and Raven (2012) distinguish two types of empowerment: the *fit and conform* empowerment concerns a potentially path-breaking incremental innovation that becomes competitive within the socio-technical environment of the incumbent regime. Instead, the second type of empowerment undermines the incumbent regime, altering the protective space into a sustainable innovative niche that *stretch and transform* the prevailing socio-technical system. The stretch and transform empowerment is not only an internal niche process; it is also influenced by destabilizations at the regime level generated through pressure exerted by the landscape (Smith et al., 2010).

Institutional reforms and external influences on the regime are key elements for the transition to clean technologies. This context is characterized by costly and uncertain research and innovation activities, and non-competitive markets for their deployment. This is because traditional technologies are economically affordable and supported by well-established groups of interest within the incumbent regime. Moreover, clean technologies should be considered as public goods because of their positive externalities for society (Knight, 2010; Shellenberger *et al*., 2008; Acemoglu *et al*., 2009); therefore, they need regulation and non-monetary incentives. Socio-technical transition is not a simple and linear process (Smith et al., 2014), but a rather complex political negotiation (Smith and Raven, 2012) between actors with conflicting positions and opinions, and it depends on how the institutionalizing process of innovation is framed and defined (Hajer, 1995).

Overall, introducing clean technologies that reduce environmental impact in an incumbent socio-technical system based on mass consumption and production utilizing fossil fuel inputs, is more a fit-and-conform type of transition; these innovations, although being radical, just postpone the problem of resource scarcity for some other decades, but they do not solve it. The changes that entail transition must be systemic, focusing on the whole value chain, and involving all actors as central to the development of stretch-and-transform path-breaking innovations. The latter must include: i) substitution of fossil fuel resources with renewable and biological resources, ii) introduction of clean technologies in the production process, iii) reduction of consumption, iv) valorisation of waste. As we shall argue in this chapter, these are four fundamental pillars of the transition to a bio-based economy.

1.3. The transition to a bio-based economy

For the deployment and diffusion of one radical innovation a single niche deals with the inertia of the socio-technical regime, while for the transition to a bio-based economy, which is composed of a wide range of economic sectors, several niches that support each other conflict with the incumbent socio-technical system. Indeed, within the sectors involved in the bio-based economy, several niches operate developing different technologies for exploiting renewable biological resources. In view of a holistic investigation of a systemic transition, one should avoid assessing sectors involved in bio-based economy separately, but rather the system should be assessed as a whole. Indeed, the complexity of the transition process of the system under investigation stands on the co-existence of several connected sectors (bio-fuels, bioenergy, bio-chemicals, biomaterials, waste management, sustainable feedstock production - biomass, etc.) coupled with the high variety of socio-economic actors operating within these sectors (rural communities, waste collectors, consumers, industry, research institutes, environmental associations, etc.).

Nonetheless, in the various definitions of the bio-based economy provided by national and international bodies, attention is often placed on specific aspects, hence sacrificing the holistic approach. According to the definition of OECD that focuses on the role of biotechnologies, *"a bioeconomy can be thought of as a world where biotechnology contributes to a significant share of economic output"* (OECD, 2009). This statement, while focusing on the key role of bio-technologies, creates problems in defining the role of agriculture (Hausknost et al., 2017) as the bioeconomy is defined as a technology-driven concept. Instead, BECOTEPS (BioEconomy Technology Platforms) defines bioeconomy as *"… the sustainable production and conversion of biomass, for a range of food, health, fibre and industrial products and energy. Renewable biomass encompasses any biological material to be used as raw material"* (BECOTEPS, 2011). This definition focuses on biomass production, but excludes the non-marketable biodiversity conservation, water quality and landscape (Jordan et al., 2007; Brunori, 2013). Moreover, the European Union Commission in its official strategy - *Innovating for Sustainable Growth: A Bioeconomy for Europe* - states that bio-based economy *"… encompasses the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy"* (EU Commission, 2012), hence paying more attention on value-added products. The two latter definitions, although using either bioeconomy or bio-based economy, both emphasise a resource-driven concept based on the transition from a fossil-based to a bio-based economic system (Hausknost et al., 2017).

Diverging visions emerged from these definitions are generated by the different rationales used for explaining the development of the bio-based economy (Pfau et al., 2014). Pfau et al. (2014) found out that as main driver for developing a bio-based economy adopted in the literature concerns the reduction of dependence on fossil fuel resources based on three particular topics: i) the decrease of the available resources, ii) the increase in the costs of exploitation of fossil fuel reserves because more difficult to reach, and iii) the location of the reserves in geopolitically unstable regions. In this case, bio-based economy is expected to develop alternative (bio-based) resources with the help of innovative biotechnologies. A further driver discussed in the literature reviewed by Pfau et al. (2014)

is strictly related to population growth and concerns the secure supply of energy and commodities as well as food security. This latter driver focuses on availability of resources coupled with the production of industrial products and energy over biodiversity and quality of environmental aspects. Both drivers emphasise the economic interest in the development of a bio-based economy and less sustainability concerns.

In a multi-level perspective, these two drivers represent factors of tensions for the regime level. Regardless of the multiple interests on stake for the preservation of the incumbent socio-technical regime, the cost and uncertainties concerning traditional resources and production capacity is generating the need for alternative resources and innovative sustainable commodities. Indeed, several actors at the regime level, i.e. national and regional policy-makers, and industry, have drafted strategies and have committed for the development of a bio-based economy (de Besi and McCormick, 2015; Hausknost et al., 2017).

Moreover, another driver discussed in the literature involves environmental concerns with a particular attention on the reduction of GHG emissions. It is assumed that the development of a bio-based economy conserves the global climate system by creating added value through the reduction of negative environmental impacts of energy consumption, production processes, and waste disposal. This driver, in a MLP, symbolize the landscape level that applies pressure on destabilizing the regime because environmental issues go beyond one system's power to mitigate pollution, thus it is perceived as an external influence that help the niche break through the incumbent socio-technical regime.

Meanwhile, in the next section we are going to discuss the developments and challenges at the niche level of the several sectors composing the bio-based economy in order to assess the transition process to a bio-based economic system.

1.3.1. Transition challenges and need for policy strategy

The divergences in market share of fossil-based fuels and products respectively to their bio-based alternatives (Langeveld et al., 2010) show on the one hand that the development and diffusion of a bio-based economy is at its early stages, and on the other hand, that barriers to the development and expansion of a bio-based market still exist (Calvert et al., 2017). Moreover, different sectors of the bio-based economy have reached different stages of development. For instance, the efforts engaged in the energy sector to produce bio-fuels as a consequence of oil shocks in the 1970s (Calvert et al., 2017), are different from the efforts in the bioplastics sector, that has a more recent development. However, in spite some remarkable cross-sectoral differences, all bio-based sectors still face significant economic, infrastructural, and social barriers. For this reason, there is indeed the need for direct public policy intervention to boost the development of the bio-based economy.

The level of maturity of the bio-based economy niches, based on knowledge, networking, and expectations according to the SNM, determines their ability to overwhelm these barriers; however, niche maturity can be accelerated through public intervention.

1.3.1.1. National, regional, industrial, and social strategies

Actors at all levels of governance have developed several strategies for the development of a bio-based economy. From "The Bioeconomy to 2030: Designing a Policy Agenda. Main Findings and Policy

Conclusions" of OECD and "Innovating for sustainable growth: a bioeconomy for Europe" of the EU, to national and regional agendas that apply the general principals of these strategies focusing on local capacities, strengths, and resources (de Besi and McCormick, 2015; Doloreux and Parto, 2005), are committed in achieving a transition to a bio-based economy. In addition, industrial actors, being in the frontline of this transition, are engaged in developing industrial strategies for better tackling the challenges and achieve a bio-based development across sectors. Among others, the Confederation of European Paper Industries (CEPI) developed "Unfold the future: 2050 roadmap to a low-carbon bio-economy" in 2011, the Bio-based Industries Consortium (BIC) developed "The Bio-Based Industries Vision: Accelerating Innovation and Market Uptake of Bio-Based Products" in 2012, and in 2013 Essent published "Natural power: Essent and the bioeconomy".

However, the core actors of the bio-based economy transition process, farmers organisation and civil society and consumers, as well have developed their techno-political agenda that is based more on social and environmental sustainability rather than on sustainable economic growth (Hausknost et al., 2017). For this reason, in order to influence the EU research and funding agenda on bioeconomy, the European organics industry established the "Technology Platform for Sustainable Organic and High Welfare Food and Farming Systems (TP Organics)" officially recognized by the European Commission (TP Organics, 2014). Other movements launched by the civil society and farmers, part of the same agro-ecologic approach to bio-based economy even though with some political-economic contradictions (Levidow et al., 2012) respectively to TP Organics, are Via Campesina and the Food Sovereignty Movement.

1.3.1.2. Strategic Niche Management in the bio-based economy niches

As far as knowledge is concerned, the various bio-based economy strategies at all levels have highlighted the importance of boosting research and innovation for generating high level of knowledge as a driver for the development of the bio-based economy (de Besi and McCormick, 2015). Indeed, the EU extended its new economic paradigm of a knowledge-based economy discussed in the 2000 Lisbon Agenda with the objective of making Europe leader in innovation, into a knowledge-based bio-economy (KBBE; EC, 2005). Key fields of research that have been developed particularly are biotechnologies and life science solutions in order to improve conversion technologies, to explore new raw materials as biomass, and to develop new ways of using efficiently biological resources (EC, 2002). As for all radical innovations, research is expensive, risky, requires long timeframes, and deals with uncertain markets (Mazzucato, 2015; Hopkins and Lazonick, 2012). In this context public intervention can mitigate two barriers: one related to investments in R&D and financial incentives, and another concerning infrastructure for production plant and industrial processes conversion and pilot test areas to increase the level of technological readiness. As a consequence, a mature technology and industrial production are achieved that lower the price of bio-based products[1] making them price competitive compared to traditional products.

A particular aspect of technological maturity is related to technological commercialisation for market-uptake. This aspect involves a strong collaboration between research institutions and industry among all bio-based sectors, building a strong network of technology transfer and knowledge share. Indeed,

[1] Bio-based products here is used as a generic term referring to all biotechnologies, bio-fuels, bioenergy, biomaterials and bio-products in general.

as identified in de Besi and McCormick (2015), national, regional, and industrial strategies for the development of the bio-based economy emphasise the engagement of actors at all levels to collaborate by means of research programmes, innovation networks, and the formation of industrial and research clusters.

A further key mechanism for the development of bio-based economy niches concerns the convergence of expectations among actors at all levels. According to Loobarch (2010), institutional fragmentation and policy incoherence in transition processes are major obstacles for long-term perspectives and collaborations. In this context, industrial actors demand for regulatory and supportive policies and coherence between policy measures and levels of government. The EU and national strategies have addressed this issue by undertaking actions for the realisation of interdepartmental panels and coordination between ministries and various departments. Moreover, an important factor for building a common vision for the future of the bio-based economy, as mentioned in section *1.2*, is the pressure and technological breakthroughs in different niches of the bio-based sectors that influence each other. The success in one niche, increases positive expectations on the development of a bio-based economic system by means of technological and knowledge share (Wellisch et al., 2010; Schmid et al., 2012; Pfau et al., 2014) and networking with powerful actors.

1.3.1.3. Society in the bio-based economy system

The creation of new markets and the uptake of bio-based economy as a common vision of the future is grounded on society inclusion in bio-based activities. There are three elements that make society essential for a transition to a bio-based economy. The first one is related to over consumption. Energy consumption, for example, that amounts to 500EJ cannot be satisfied by the energy produced with biomass grown on land that is estimated to 450EJ in a context of increased efficiency in food and harvesting systems and by increasing the surface of arable land for dedicated biomass production (Berndes et al., 2003; Deng et al. 2015, Calvert et al., 2017). A second element concerns awareness and responsibility on waste differentiation and recycling, particularly organic waste. In view of a systemic transition to bio-based economy, a life-cycle perspective based on the cascading approach and the valorisation of waste as raw material for a new product requires an active participation of the consumers. The third element deals with quality of performance, safety and security of bio-based products[2]. Innovative products that have no clear characteristics are not easy for consumers to accept, however, it depends also on consumers' awareness and bio-products[3] prices (Almenar et al., 2010; Sijtsema et al., 2016).

The simple replacement of fossil fuels with biomass, without other systemic changes, is not an answer to the drivers that boost the development of a bio-based economy. For this, there is the need to stress the sustainability and environmental benefits that are closely connected to production processes and consumption patterns.

1.3.2. Criticisms on sustainability

Although the transition to a bio-based economy is implicitly considered sustainable, there are some aspects of production processes and consumption behaviours that are not. The production and

[2] ibidem
[3] ibidem

utilisation of biomass that is at the basis of a bio-based economy is introduced in a critical debate concerning indirect land-use change. Although the production of bio-fuels and products requires dedicated non-food crops, the land surface for food and non-food crops is limited, thus the controversy food vs. fuel still holds (Pfau et al., 2014). Even the use of marginal land, albeit not in direct competition with food production, can generate negative impacts on biodiversity (Raghu et al., 2011; Schmid et al., 2012; Sheppard et al., 2011). Especially in a future perspective when the population is estimated to increase and as a consequence either food or energy consumption will increase, the sustainability concept of a bio-based economy grounded only on the substitution of fossil fuels with biomass will not stand anymore.

Against this framework, there are some alternative options that require the involvement of actors at all levels and the collaboration among all sectors in order to reach sustainability through the concept of a bio-based economy. In line with the EU 2020 strategy that demands for smart, efficient, and sustainable growth, the cascading approach can be used to increase resource efficiency while employing the same feedstock for both materials and fuels (Keegan et al., 2013). The core principle of cascading is the utilization of biomass at first for high value applications, like the production of bio-based products, and in a final step it can be converted into energy source. To reach high levels of resource efficiency, a crucial step is the development of integrated biorefineries using cascading principle (Sirkin and Houten, 1994).

Another option for reducing the quantity of dedicated crops as biomass for industrial production is the exploitation of waste and agricultural residue streams (de Besi and McCormick, 2015). This alternative in particular requires a strong collaboration on one hand, among sectors bringing agriculture and industry together for creating the opportunity to use waste streams and agricultural residues for bio-based activities, and on the other hand, among actors for strategic and financial support in infrastructure that allows a complete exploitation of biomass.

Finally, the fossil carbon consumed today cannot be fully substituted neither with agriculture and forest alone, nor with the additional use of innovative forms of biomass such as micro and macro algae (Staffas et al., 2013). In this context, one solution provided to the limits of a full development of a sustainable bio-based economy can be the retreat of the human activity within the biophysical boundaries, therefore an overall reduction of material consumption in industrialised countries in particular (Daly, 2005; Rockström et al., 2009; Gudynas, 2011; Muraca, 2012; Neumayer, 2003). As mentioned in section *1.3.1.3*, our society is overconsuming generating an increase in fuels, materials, products demand and waste, thus there is space for a decrease in consumption.

Overall, the transition to a bio-based economy cannot be considered the only solution to environmental and socio-economic issues, however it represents one important piece in the jigsaw puzzle of systemic sustainability transitions for tackling challenges and build a playing field for sustainable actions.

1.4. Aim and structure of the thesis

Understanding the path to sustainability transitions is among the main goals of the literature in socio-technical systems. Although scholars have developed a thorough analysis of the dynamics of sustainability transitions, there remain some gaps in the literature because of the complexity of the process and the large number of actors involved, which are characterized by different socio-economic context, cultures, habits, and artefacts. Against this framework, this PhD thesis is introduced in this literature with the aim to enrich the analysis of the path to sustainability transitions focusing particularly on the policy influence on niche maturity and structure, and the role of space in niche empowerment. Identifying the importance of policy on transition patterns and systemizing the role of space on niche maturity are of great interest for the comprehension of a socio-technical system and consequently of the mechanisms influencing the transition process.

Having this in mind, this thesis is composed of three core chapters, from Chapter 2 to Chapter 4, that apply different research methodologies and data elaboration, providing new findings and discussion, and a concluding paragraph presenting the Key Findings and Conclusions.

After a thorough presentation of the theoretical background in the introductory chapter of this thesis, Chapter 2 investigates the transition process to clean energy technologies in the Boston area. Using an Argumentative Discourse Analysis based on official documents and qualitative interviews with key stakeholders, the research shows that the clean energy niche in the Boston area is generally perceived as strong and well developed. However, it has not been able yet to break through the incumbent socio-technical regime. Putting together the public legitimizing and de-legitimizing narratives, what comes out refers to two gaps at the policy level; one concerning an effective commercialization programme for the deployment of clean energy technologies locally, and the second one is related to crowding-in private investments facilitating a fruitful entrepreneurial environment and stimulating the development of dedicated infrastructures for the deployment of innovative clean technologies.

For instance, these two aspects (on the one hand, the space of development and deployment of innovative technologies, and on the other hand, the role of public policy for successful innovations) have been addressed in the following Chapter 3 and Chapter 4, specifically the emerging importance of the spatial dimension on niche empowerment and the influence of policy intervention in niche architecture.

Indeed, Chapter 3 focuses on how the spatial dimension of niche actors' networks influence niche emergency and maturation, hence affecting the transition process. The idea behind this chapter is that space and scale are crucial in order to understand the timing of emergency and maturity of technological niches, determining their ability to break through the incumbent socio-technical regime. To assess the influence of the spatial dimension on niche empowerment, an agent-based model is developed, locating agents in a geographical space and connecting them based on absolute (geographical) or relative (social, cognitive, institutional, organizational) proximity. As a result, three types of niches are addressed - local, global and local-global – that are characterized by different timing in the adoption of the innovative technology, different velocity in niche maturity, and different stability of network. Therefore, a spatial dimension of the niche should be considered as a third mechanism within the Strategic Niche Management.

Moreover, in Chapter 4 the influence of different policy strategies on the structure of an emerging bioplastics niche is assessed. A comparative analysis, looking at Italy and Germany, is conducted because both countries have enacted divergent policies in support of the bioplastics industry. The Social Network Analysis is used for the comparison and some interesting insights on the maturity level of the two respective niches as well as on the emerging architectural properties of the underling social networks are emphasized. These results are related, in the authors' view, to the different policy strategies followed by national governments in the two countries: the German case being characterized by large public investments in R&D, whereas the Italian case mostly characterized by demand side policy which effectively created a market for bioplastics.

Lastly, in the Key findings and conclusions are elicited some general conclusions on the sustainability transitions process based on the main findings of the abovementioned chapters.

Chapter 2

Patterns of clean energy transition in the Boston area

Global economic and population growth trends are placing pressures on the natural environment, threatening future economic and social development. According to the *World Population Prospects 2015*, the world population reached 7.3 billion in mid-2015, implying that the world has added approximately one billion people in the span of the last twelve years. It is expected that this trend will continue over the next 30 years, with the world's population projected to increase by more than one billion people within the next 15 years, and to increase further to 9.7 billion by 2050 (United Nations, 2015). Almost 80% of the world's population will be concentrated, by 2050, in Africa and Asia – the two regions of the world experiencing the highest GDP growth rate (IMF, 2016). A major consequence of these two trends is higher consumption and demand for a large number of commodities and manufactured goods, with pollution levels and the depletion of available natural resources increasing in parallel (Morone, 2016).

Scientists, analysts and policy makers are taking stock of these trends, trying to push society towards more efficient as well as sustainable development patterns. However, this requires a radical change in the world's production system and the employment of innovative technologies in order to trigger sustainability.

Indeed, the aimed-for sustainability transition is a rather complex and long-term process passing through the development of clean technologies, their adoption by the market, and their diffusion supported by public intervention. Clean technologies are defined as "*all the techniques, processes, and products that are of importance in preventing or reducing the burden on the environment*" (Schot, 1992). For instance, the rapid deployment of clean technologies faces different challenges, mainly linked to public responsibility (Veugelers, 2012).

Clean technologies are in direct competition with old and traditional technologies that have already installed infrastructures, are very often less expensive (due to scale economies), more stable, and better known by the market. These rivalry aspects are detrimental for clean technologies to take over the market, and should be mitigated by the policy makers' efforts to incentivize the shift to a more sustainable society. Moreover, there are significant sunk costs generated by old infrastructures that cannot be replaced merely by incentives; they also need public support for market restoration (Mazzucato, 2015; Hopkins and Lazonick, 2012). In addition, clean technologies need considerable amounts of resources for research that has a long-term perspective and is often highly risky, thus not attractive for private investment; nonetheless, it can be a strategic decision for policy makers (David *et al*., 2000).

In this chapter we investigate the transition process to clean technologies thorough the lens of the multi-level perspective (MLP), focusing on energy technology industries located in the Boston area. Both the choice of the analytical framework - MLP, and the unit of analysis - the Boston area - for this study are not random. As broadly discussed in section 1.1, MLP allows capturing the complexity of interlinked relationships which affect socio-technical transition processes as well as their underlying driving forces, and thus serves the purpose of our study. While the Boston area because it is considered a leading region in research and innovation concerning clean technologies in the energy sector, second only to California in the US. Nonetheless, this area generates only 10.5% of its net electricity from renewable energy resources, less than the US average which stands on 15.9% (US EIA, 2016), showing a mismatch (or incomplete transition) between technological development and deeper societal changes.

Against this framework, the main goal of this study is to pinpoint the factors that hinder the transition to a complete deployment of clean energy technologies in the Boston area. Since innovation assessment faces methodological challenges, and the circumstances boosting innovation can be of various origins and not always quantitative (Knight, 2010; Rosenberg, 1994), we shall use an Argumentative Discourse Analysis (ADA) to illustrate the emerging clean energy niche in the Boston area. We shall focus particularly on policy intervention, analysing the emerging discourses of niche actors (mostly institutions), external actors supporting its development, and those hindering it.

The remainder of the chapter is structured as follows. In Section 2.1 we describe the multi-level structure shaping the clean energy technologies in the Boston area. In Section 2.2 we discuss the discourse analysis method used for this study, while in Section 2.3 we examine the emerging storylines constructed, with the help of the ADA approach. Finally, we conclude with a discussion of the results in Section 2.4.

2.1. The multi-levels of clean energy technologies: identifying niches, regimes and landscapes in the Boston area

In order to give a complete view of the case study considered, before introducing the discourse on the development of clean energy technologies, we will provide a brief description of the main actors in the landscape, the surrounding regime and the clean energy niche in an area (Figure 2.1) comprising the city of Boston, the city of Cambridge, the city of Somerville, the neighbouring cities and all the surrounding suburbs – where numerous universities, research centres and firms are located. The Boston area is neither a statistical nor an administrative unit; it is a delimitation of the western part of the state of Massachusetts (USA) used in several scientific papers and suitable for the purposes of this study. As pointed out by Berry et al. (1969) and Owen-Smith and Powell (2004), we can define the Boston area as a Functional Economic Area, which has a certain gravitational and commuting influence on the surrounding areas. With this geographical focus in mind, we try to illustrate the historical evolution associated with the development of the clean energy niche.

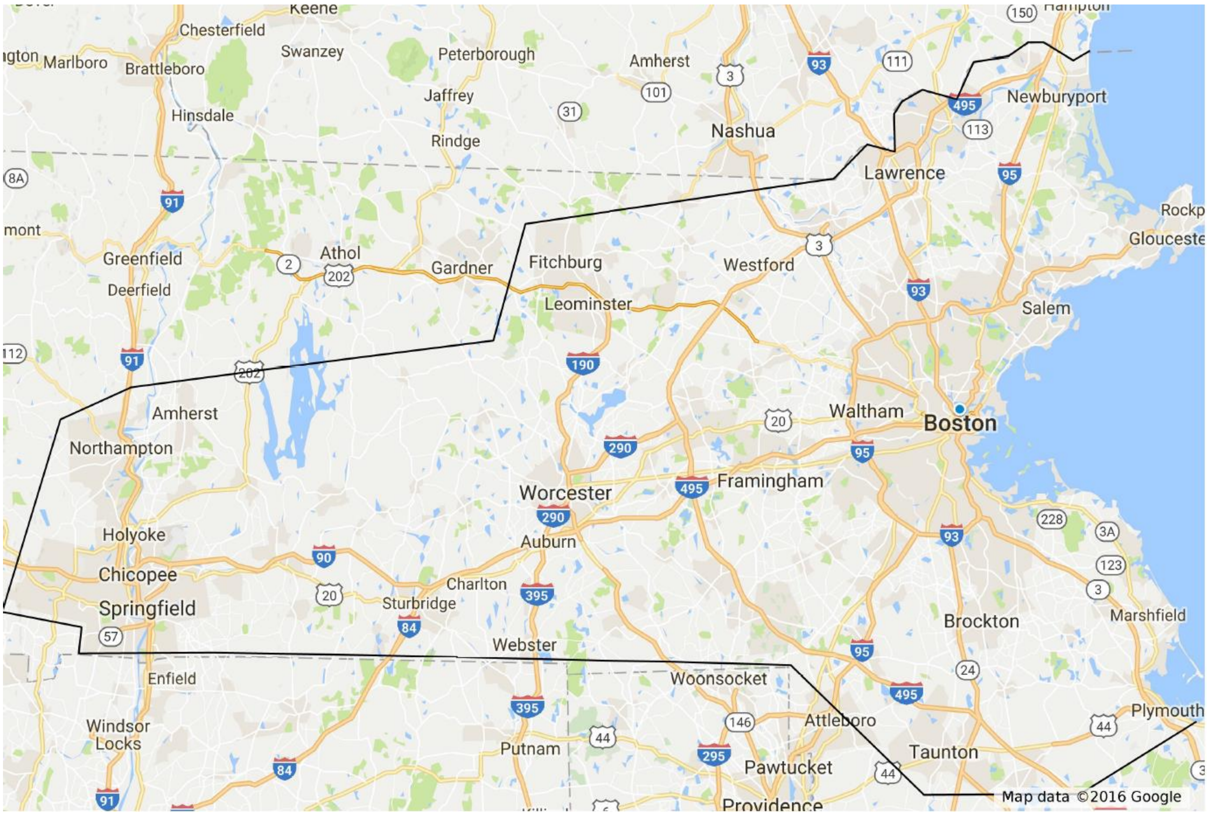

Fig. 2.1 The Boston area

2.1.1. The landscape

There have been several conditions at the landscape level that have often, but not always, encouraged the development of clean energy technologies in the Boston area.

The ambition of the US government to retain a leading international position in global markets has pushed it to be directly involved in and encourage technological developments, research and innovation. In particular, globalization trends have forced the US market, which is a mature economy, to abandon traditional production approaches and focus on knowledge and innovation in order to remain a world economic leader (Mazzucato, 2015). Indeed, in order to support employment and economic development, innovation has been the main driver of public policy in the US since the 1980s. Since then, the Federal government has supplied significant funds to basic and applied research for particularly innovative projects and start-ups via different federal agencies (e.g. the National Science Foundation - NSF; the Small Business Innovation Research Program – SBIR, etc.). This economic trend, coupled with the emergence of environmental issues as a top priority need, have created a situation in which State and Federal institutions have acquired a central role in the raise of a clean energy niche.

Indeed, environmental issues started growing relevance on the US federal government agenda since 1970, when the Environmental Protection Agency (EPA) was established and the National Environmental Policy Act was adopted; this was mainly as a consequence of the 1969 Santa Barbara oil spill. In addition, several environmental laws were adopted as a result of the Stockholm Conference and its *Report of the United Nations Conference on Human Environment* in 1972, which required participating nations to resolve environmental issues of common concern. Further international conferences on environmental issues have further put pressure on the US to strengthen its policy on environmental protection (such as the Kyoto Protocol in 1997).

Environmental issues further gained momentum in the second millennium, when, as a result of internal pressure coming from the emergent clean energy niche, coupled with an international increase in energy use - and thus in the demand of clean energy technologies from developing countries (IEA, 2004-2016), the US government decided to expand the domestic production of clean energy technologies in order to export them. To this aim, the adoption of the Energy Policy Act in 2005 by the US government intended to extend to renewable energies federal production tax credit, and involved stakeholders from different groups of interest and public agencies concerned with environmental regulation and incentives. Although promising, this Act eventually had no real effects or regulation on the energy sector. In fact, according to the Union of Concerned Scientists (Carley, 2011), the $14.5 billion provided for the implementation of the bill were spent mainly on nuclear and fossil fuel, with only 9% on renewable energy and 21% on energy efficiency. Moreover, in 2008, the US Congress decided to contribute to the Clean Technology Fund of the World Bank with $2 billion over five years to fund large-scale investments to encourage the deployment and transfer of clean energy technologies in developing countries (World Resources Institute, 2010). In addition, at the COP21 climate conference in 2015 in Paris, 21 participating countries, including the US, launched Mission Innovation, the goal of which is to "*reinvigorate and accelerate public and private global clean energy innovation with the objective to make clean energy widely affordable*" (joint statement, Mission Innovation), with the commitment to increase clean energy research and development. This initiative has also allowed the US government to start signing bilateral agreements on the manufacturing and export of clean energy technologies.

2.1.2. The regime

The definition of "regime" used here is based on two dimensions: the geographical one, which for the focus and scale of this case-study matches with the state of Massachusetts, and the socio-technical one that is composed of institutions, regulations, policy and traditional markets and infrastructures.

Concerning incumbent markets and infrastructures for energy, Massachusetts is highly dependent on external sources, considering that energy consumption in this State exceeds production. The State does not produce any petroleum, coal or natural gas, yet its net electricity generation depends on natural gas for 74%, on petroleum for 0.3%, on nuclear for 15.5% and only for 9.5% on renewables, mainly hydroelectric and biomass facilities (US EIA, 2017a). Moreover, Boston, the biggest city in the State, has the oldest port continuously active in the US that has petroleum products terminals, and Massachusetts has the only liquefied natural gas (LNG) import terminals and the largest coal-fired power plant in New England.

However, data show that path-breaking events are emerging. For instance, the per capita energy consumption level in Massachusetts is lower than in other states in the US, ranking 43rd out of 51 US States (ranked in decreasing order), with 224,727 MJ of energy consumed in 2015 (US EIA, 2017b). This performance is due mainly to: energy efficiency (Massachusetts State being the best performing State in the nation for six years in a row) (MassCEC, 2016), conservation programmes and environmentally friendly legislations (e.g. the Commonwealths current 2016-2018 Three-Year Energy Efficiency Plan, the Affordable Access to Clean and Efficient Energy Initiative, etc.) (EEA, 2017). Most importantly, in 2008 the government of Massachusetts adopted the Green Communities Act that promotes the development of renewable energy, energy efficiency and conservation, "green communities", and the implementation of the Regional Greenhouse Gas Initiatives. The intent of this

Act is to create a competitive market for renewable energy suppliers and energy efficiency programmes. Another example in this regard is funding provided by the Massachusetts Clean Energy Centre (MassCEC; see Table 2.1), which aims at developing new sustainable products and specialized labour.

Tab. 2.1 MassCEC Grant Programmes

Grant Programme Name	Target	Grant Amount
Catalyst	To help researchers and young companies develop prototypes and proof-of-concept studies	$2.1 million to 55 companies
AmplifyMass	To support Massachusetts-based awardees of ARPA-E (Advanced Research Projects Agency-Energy)*.	$3 million to 14 awardees
AccelerateMass	To support graduates in the transition out of accelerator programmes	$50,000 in phase 1 and $100,000 in phase 2
InnovateMass	To help young clean energy and water companies overcome financial barriers to commercialize products and technologies	$2.2 million to 19 companies
DeployMass	To help companies seeking a first or early customer to validate the commercial readiness of their technology	up to $160,000
Direct Equity Convertible Debt Investment	To help early stage companies	average investment of $500,000
Venture Debt Investment Program	To fill funding gaps for clean-tech companies who are looking for venture debts but cannot attract private venture capitals	from $100,000 to $1 million

Note: ARPA-E objective is to advances high-potential, high-impact energy technologies that are too early for private-sector investment. ARPA-E awardees develop entirely new ways to generate, store, and use energy.

Source: Based on data from MassCEC.

However, both examples show that the policy at the State level has been engaged more in regulation rather than in infrastructural renovation, especially when considering that the MassCEC funding neither supplies testing areas nor build infrastructural facilities for the start-ups population composing the clean technologies niche.

2.1.3. The clean energy niches

From 2008 to 2015, the capacity to generate electric power with renewable resources in the Boston area passed from one-twentieth to one-tenth, an increase which reflects also in employment terms: the clean energy industry employs nearly 99,000 clean workers in 6,439 establishments located across the State, of which 91,278 workers in 5,888 establishments are located in the Boston area. At the same time, although the proportion of R&D and engineering in clean energy in the Boston area is higher than in other parts of the State, the clean energy industry is hiring people with less experience and education than the one desired, indicating a deficit in the skilled labour supply for clean energy (MassCEC, 2105a).

However, there are seven federal research academic institutions in the city area conducting theoretical and applied clean energy research, helping to counter this deficit. This research involves not only an intensive innovative activity in the pre-commercial phase, but also turned into a mature technology transfer which amounted to 147 patents awarded to 36 companies that work with pre-commercial products, 229 patents held by firms focusing on energy efficiency and 25 patents held by establishments working exclusively with energy goods and services (MassCEC, 2015a).

Overall, the clean energy niche in the Boston area is characterised by a fast growing and dynamic innovation environment. In particular, the development of clean energy technologies has been boosted by local research institutions that can at all times provide innovation, specialized workforce, laboratories and equipment. Important actors in the fast evolution of clean energy niche are universities, technology business incubators, and clean-tech business accelerators, which supply start-ups, in addition to the space for developing their prototypes or their business plan, with resources from and networking with strategic partners in order to survive and become mature. The North Shore Innoventures is one of the incubators engaged in mentoring, support services and well-equipped laboratories. Cleantech Open Northeast is the world's oldest and largest clean-tech business accelerator, which provides training and funding opportunities. Greentown Labs is an incubator for clean-tech start-ups that has raised $25 million in investment capital for its client companies (MassCEC, 2015b). Additionally, there are other incubators and accelerators of start-ups, such as the Cambridge Innovation Center (hosting 600 new companies), Roxbury Innovation Center (situated in a poor and marginalized neighbourhood), Venture Café, MassChallenge and the Boston Innovation Center, which are all supported by the state of Massachusetts and the municipalities as part of their innovation policy initiatives.

2.2. Qualitative Discourse Analysis Method

Moving within this multi-level framework, we will investigate the transition process to clean technologies in the Boston area by applying the Argumentative Discourse Analysis (ADA) first proposed by Hajer (1995), subsequently developed by Hajer and Versteeg (2005), and further applied by Rosenbloom et al. (2016), Cotton et al. (2014), Usher (2013), Bern and Winkel (2013), Hunold and Leitner (2011), Jessup (2010), Mander (2008), and Szarka (2004).

ADA is a valuable methodology in critically examining the environmental discourse embedded in the analysis of energy policies. For instance, ADA by examining discourses of key actors who are part of the context, expresses contradictory discourse and conflicts formed around particular opinions on environment. The main component of ADA is the storyline, which is a narrative sustained by a socio-political coalition and plays a crucial role on "clustering of knowledge, positioning of actors, and ultimately, in the creation of coalitions amongst the actors of a given domain" [23]. Storylines of the environmental discourse are characterized by specific emblems or "issues that dominates the perception of the ecological dilemma in a specified period" [23]. Since storylines emerge between and among political boundaries and does not conform to specific political and institutional settings they are very helpful in investigating the influence of a mature niche on the struggling elements of the incumbent regime, by revealing the hegemonic ways of arguing in an environmental conflict.

Hajer (1995) distinguishes 10 tasks to undertake an ADA. These tasks can be generally summarized in three main steps. The first consists of a first preliminary assessment of the context and its development by analysing written documents and official communications. Hence, in order to explore the clean energy technologies context in the Boston area, we reviewed: reports[4], studies and analyses[5], industry roadmaps[6], newspaper articles[7], and websites[8] (see Annex 1 for a full list of the documents consulted).

A second step for carrying out an ADA consists of interviews with key players in order to collect more information on specific events, which, in our case, might affect the sustainability transition towards a clean energy sector. Initially, based on the preliminary findings of the review of the "grey literature" (i.e. reports, official documents, industry roadmaps, newspaper articles, and websites), I conducted a follow up qualitative interview with two experts with a long-term expertise in the field of clean energy who were asked to validate or confute the set of actors preliminary identified and categorize them according to the type of pressure exerted. As a result, we identified 12 key actors in the development and deployment of clean energy technologies in the Boston area with whom we conducted formal interviews using a qualitative, semi-structured questionnaire (see Annex 2 for a full list of the interview questions). The interviews were carried out between June and July 2016.

Figure 2.2 gives a graphic image of the types of actors interviewed as part of this step, allocating them to three closely related niches and distinguishing for each niche between core and peripheral actors.

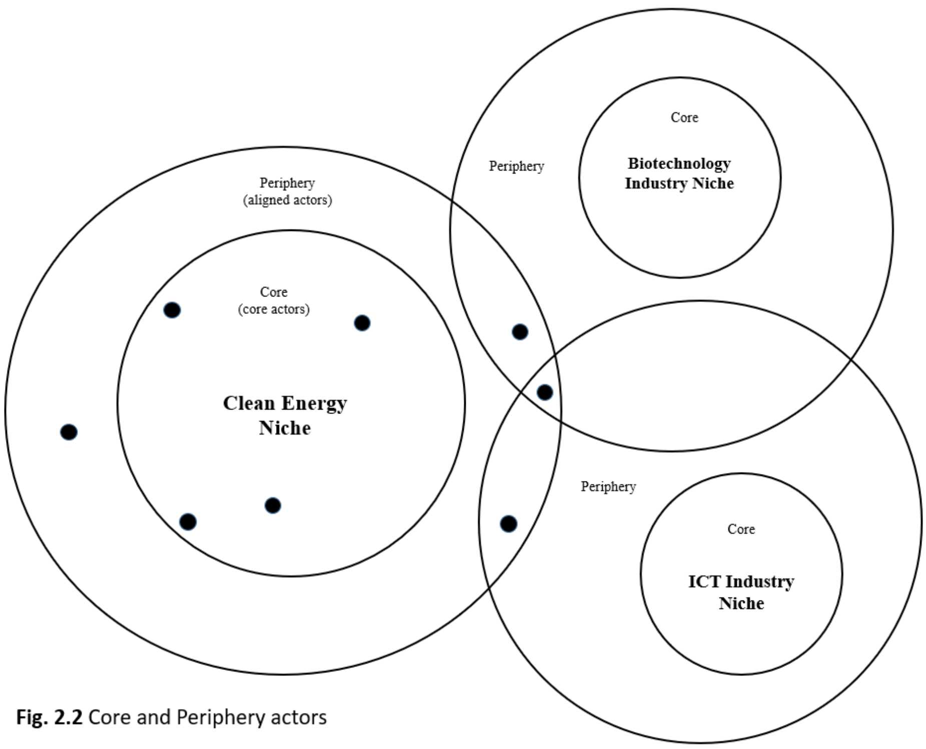

Fig. 2.2 Core and Periphery actors

Source: Based on Rosenbloom *et al.*, 2016.

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[4] E.g. Massachusetts Clean Energy Industry Report, 2015, "TURA 25th Anniversary Leaders Demonstrate Product Innovation, Quality and Safety".
[5] E.g. "The Impacts of the Green Communities Act on the Massachusetts Economy: a review of the first six years of the Act's Implementation", "Massachusetts Energy Profile".
[6] E.g. Massachusetts Water Technology Industry Roadmap.
[7] E.g. The Boston Globe.
[8] E.g. Energy Storage Association website, Northeast Clean Energy Centre website.

As shown in Figure 2.2, four of the selected actors are classified as part of the 'core' of the clean energy niche, which develops and diffuses the innovative technology (Rosenbloom *et al*., 2016: 1279). This group of actors is composed of three technology transfer offices (Harvard University, MIT, Northeastern University) and one clean technology business accelerator (Greentown Labs). The figure also shows that, of the twelve actors interviewed, three are placed right in the middle, between the niche and the regime, thus at the 'fringe' of the niche (Rosenbloom *et al*., 2016: 1279); this is because they are part of initiatives that promote the development and deployment of clean technologies, but not as direct producers (New England Water Innovation Network, Venture Café Foundation and The Massachusetts Technology Transfer Centre).These actors, for instance, also operate in technology transfer and in the promotion of new technologies and start-ups in support of other niches, such as the ICT or biotechnology niches. Peripheral actors, on the other hand, operate at the intersection of clean energy, ICT and biotechnology niches. The third and last group of interviews is composed of five actors who are part of the regime (Massachusetts Clean Energy Centre, Environmental Protection Agency, Massachusetts Technology Collaborative: Innovation Institute, Office of Technical Assistance and Technology and Boston Redevelopment Authority). The persons within these organizations interviewed were selected because of their strategic role with respect to the mission of their organization – e.g. responsible for grant programmes, manager of projects in innovation and industry support, or clean technology officer.

For the sake of clarity, we provide the list of the 12 key actors' organisations interviewed for this study in Table 2.2.

Tab. 2.2 List of key actors' organisations

Niche Actors	Periphery Actors	Regime Actors
Technology Licensing Office, MIT	Massachusetts Technology Transfer Center	Massachusetts Clean Energy Center
Center for Research Innovation, Notheastern University	Venture Café Foundation	Environmental Protection Agency
Harvard Office of Technology Development	New England Water Innovation Network	Innovation Institute (Massachusetts Technology Collaborative)
Greentown Labs		Office of Technical Assistance and Technology
		Boston Redevelopment Authority

In order to complete the ADA, a third and final step is necessary, involving the analysis of particular events or incidents that might emerge from the reviews and interviews, demonstrating the reliability of the storylines, although there may be controversial opinions or experiences. To this aim, we analysed the interviews and documents querying on discourse elements and events.

Following these three steps we were able to identify one *dominant* storyline concerning flourishing dynamics of the innovation niche and *struggling* storylines. The former legitimizes the incumbent regime by highlighting the commitment of public intervention, while the latter delegitimizes the engagement of public bodies showing a lack of empowerment of the clean technologies niche. The identified storylines are completed by quotes from the interviews and reported in the fifth section.

2.3. Storylines of transition to clean energy technologies in the Boston Area

Building on the theoretical and empirical framework depicted above, we will now illustrate the identified discourse encompassing clean energy technologies in the Boston Area. The emerging storylines have enlightened two specific trajectories of the discourse:

1. *the way in which actors recognize the presence of a clean technology niche;*
2. *how they frame the context in which this innovation is developed and deployed.*

We identified our main storyline along the first trajectory. For the second discourse trajectory, we identified two storylines, one that *legitimizes* the role of the public intervention and another one that *delegitimizes* its commitment. In what follows we shall discuss these three storylines in some details.

2.3.1. The dominant storyline

Overall, most of the actors expressed the necessity to shift to a cleaner energy system, thus committing to a more sustainable production. According to the interviewee of MassCEC "*the breaking point with the traditional energy production is the adoption of the Green Community Act in 2008*".

Based on the ADA methodology, this specific event has influenced the development of this dominant storyline, regarding the current general development of clean technologies.

STORYLINE 1*: Clean energy technologies are central to a thick network which exchanges knowledge and engages for a cleaner common future.*

In this storyline we identified three aspects characterizing the development of clean energy technologies in the Boston area (Table 2.2). As broadly discussed in the literature, the main driver for a cleaner future and for the reduction of environmental pollution is ***building a common vision through shared expectations***. On the one hand, universities "*use commercialization of research and patents in order to encourage social use of the inventions*", and on the other hand, the State adopts environmentally friendly laws and incentives for more energy efficient and cleaner production. The annual Industry Report of MassCEC mentions specific goals for the future: "*In August 2008, Massachusetts required all economic sectors to reach a 25% reduction in GHG emissions by 2020 and an 80% reduction by 2050 under the Global Warming Solutions Act*", becoming "*one of the first States in the Nation to move forward with a comprehensive regulatory program to address climate change*", according to the Executive Office of Energy and Environmental Affairs of the Massachusetts Government.

Moreover, as stated by the Massachusetts Labour and Workforce Development, the private sector by its side "*continues the trend of becoming more 'pure-play', meaning that all of their activities are clean energy related*".

The achievement of this goal at all levels is driven by ***knowledge creation and sharing***, which consists of local learning processes and investment in human capital and a specialized labour force. The actors interviewed in the Boston area focussed particularly on *research and innovation* for two reasons: on the one hand, the development of clean energy technologies requires an intense research activity that generates radical innovation; on the other hand, as mentioned above, the Boston area is characterized by a high number of research universities. More specifically, since the US government adopted the Bayh-Dole act in 1980, universities have become key actors of innovation by means of commercializing their research to firms operating in the market. As highlighted by the interviewee of the Technology Licensing Office of MIT, "*we file about 200 patents a year and ¼ of the inventions are only in clean-tech*". Both MIT and Northeastern University license half of the filed patents to already existing companies, with 20-25% of these resulting in spin-offs. Only at Grentown Labs, a clean-tech accelerator, "*have been used 32 innovative patents and the university-born companies are 9*". The interviewee of Venture Café Foundation on the other hand argues that there is a dire need for technology transfer:

"*Clean energy in the Boston area is composed by small companies; there are no large companies yet. Therefore, technology transfer is really important because all the research and innovation comes from universities. Small companies don't have budget for research.*"

Therefore, knowledge sharing and technology transfer represent a regional competitive advantage disseminated particularly by networked actors. ***Collaboration and networking*** is quoted as an incentive, either for the location of clean energy companies in Boston, or for the success of clean energy development. This need is also highlighted by the MIT TL Officer, who declared that "*one-third of the patents are developed in collaboration with other universities or companies where our students have higher possibilities to get hired*". According to the respondent of Greentown Labs as well, their success stands on the dense network they have created, composed of 102 host start-ups and mature and specialized companies, which offer their expertise in topics that range from IP, tax filings, raising capitals to technical expertise in clean energy sector.

Tab. 2.3 Overview of dominant storyline [*S1*]

Dominant Storyline	*Clean energy technologies are central to a thick network that exchanges knowledge and engages for a cleaner common future*		
Elements constituting the dominant storyline	Universities, industry and public bodies share common expectations and are working for a cleaner future	Knowledge creation, local learning processes and technology transfer are peculiar to the Boston area	Networking is quoted as an asset for the location of clean energy companies in the Boston area

2.4.1. Legitimizing and delegitimizing incumbent regime

The core message of the dominant storyline is about the existence of a thick network of actors engaged in knowledge exchanges: this network represents the clean energy ecosystem. Moreover, a common thread of the key elements constituting this storyline, is the need to have a proactive role of public institutions and actors, which should exert pressure upon the incumbent energy regime, prompting the deployment of clean energy technologies. We further investigate this aspect, identifying two additional storylines to describe its multi-level interactions and investigate niche empowerment.

STORYLINE 2*: "Public intervention is everywhere…"*

This storyline represents the impression stated by all the interviewees. The adoption of environmentally friendly interventions has been significant in the Boston area, accounting for a large number of laws and regulations concerning air quality, toxic and hazardous substances, waste and recycling. One particular example in this regard is Toxics Use Reduction Act (TURA), which was signed into law supported by both industry and environmental groups. This Act "*requires directly to the companies to analyse and report their chemical use annually, quantifying the chemical on the final product, the chemical released to the environment at the end of the production process and if they do any waste treatment*", declared the interviewee from OTA, "*(…) and the companies have to draw up a long-term plan on pollution reduction*".

For the accomplishment of TURA's goal in innovative techniques for cleaner production is engage the TUR Institute located at the Lowell Campus of the University of Massachusetts. "*The Institute is engaged in alternative assessments, in research developing alternative chemistries, in evaluation of alternative technologies as well in order to complete their program of technology transfer*", declared another interviewee from OTA.

Additionally, with the Green Communities Act of 2008, the government of Massachusetts aimed to reduce the costs of renewable energies for the consumers and "*increase generation from low or zero-carbon resources within Massachusetts*", as written by the Analysis Group, Inc. The Green Communities Program instituted by this Act provides incentives to municipalities that engage in energy efficient and renewable technology. The Pioneer Valley Planning Commission Sustainability Toolkit mentions indeed that the Green Communities Division of the Department of Energy Resources shall provide "*up to 10 million dollars per year state-wide in technical and financial help to the communities involved*". Part of this amount is raised by the Regional Greenhouse Gas Initiative, adopted with the same Act, which uses market-based cap-and-trade emissions of CO_2. The emission allowances issued under this initiative are auctioned and the funds generated are spent as no-interest loans for municipal energy-efficiency projects.

Another aspect to be considered is that once the laws are adopted and the programmes authorized, there is need for funds in order to implement them all. Indeed, the Green Jobs Act, adopted in 2008, also introduced more than just laws and regulations: it designated "*125 million dollars to train about 30,000 people in green collar jobs*", as stated Green For All, an initiative of the Dream Corps. In order to achieve these goals, the Act instituted the Massachusetts Clean Energy Centre (MassCEC), which became "*the most important quasi-public agency in job creation and for the economic development of the clean energy industry*", as announced by the technology officers of MTTC.

According to the interviewees and the documents reviewed, the launch of MassCEC was a particular event within the development of public policy initiatives in the clean technology industry. From its creation, government intervention was not only about of regulation, targeting also employment and funding.

According to technology officers from MIT, Harvard and Northeastern University, "*80-90% of our research is publicly funded*". They continued, "*We receive most of our funds by NSF and NIH for our basic research in general, but MassCEC and SBIR are key actors in supporting our students to green collar jobs, commercializing our staff's clean patents and funding our inventors' spin-offs*".

"*Recognizing the importance of exploiting the $4.5 billion spent on basic research at the universities, research institutions and research hospitals in the state, (…) the Massachusetts legislature created and* *funded the Massachusetts Technology Transfer Centre (MTTC) in 2003*", as written on the MTTC website. In fact, the MTTC's interviewee said that "*MTTC itself does not provide funds but it supports the universities' TTOs, assists institutions which do not have their own TTOs and develops programs in collaboration with MassCEC and Massachusetts Technology Collaborative (MassTech), both quasi-public agencies, which support the programs financially*".

Indeed, the interviewee of the Innovation Institute, a department within MassTech, declared that they "*grant capital funding with a co-participation of one-third up to 5 million dollars to projects on innovation development*". He continued, "*we generally fund non-profit institutions, especially universities, which collaborate with private companies or for-profit institutions*". MassCEC also implements many grant programmes ranging from universities' innovators and start-ups to growing companies. "*MassCEC, as a quasi-public agency, provide grants and pilot test areas for GTL companies*", reported the interviewee of GTL, while the technology officer of Northeastern University mentioned that "*one of our professors has gained a $40,000 grant for the commercialization of his innovation*". As a matter of fact, "*at the federal level*", explained the technology officer of MIT, "*SBIR is a particular program of SBA which has helped a lot for the creation of spin-offs. Particularly, it funds small companies which collaborate with universities and the funding goes to the university as well*".

As for the work force qualification question, both MassCEC and the Innovation Institute have in place programmes to support students in transition to the labour market, "*because Boston has a high rate of international students who would chose to work in the Boston area only if there is a good work environment*" (highlighted the Innovation Institute interviewee). The 2015 Massachusetts Clean Energy Industry Report states that "[*T*]*he wide range of MassCEC Workforce Development Programs brings awareness of clean energy employment opportunities to help job seekers of all backgrounds obtain clean energy jobs in Massachusetts*". Indeed, since 2011, according to the interviewee of the MassCEC, this organisation has placed "*more than 1,300 interns at over 250 companies which have received a reimbursement of $14/hour for the internships*".

Public intervention also targets infrastructure and networking. As highlighted by MIT and Harvard representatives located in Cambridge, "[*T*]*he State of Massachusetts and the municipalities of Boston and Cambridge have an economic development project for the creation of an innovation district and their engagement focusses particularly in infrastructural works of connecting Kendall Square with the rest of the area by the bridge and the red line*". Similarly, the interviewee of GTL also highlighted that "*at the local level, the city of Somerville is building fab labs, which is a small maker-space, in high schools and in order to stimulate innovation they are engaging to provide also physical connections, in addition to economic ones. Moreover, in 2015, the city of Boston launched an initiative called the start-up tsar. The person responsible for this initiative, named by the municipality, has a planning background and he has been tasked to analyse the possibilities of the city to welcome start-ups and provide them with physical connections in particular*".

Indeed, the general framework of the public engagement in the development of innovative clean energy technologies is rather positive and undertaken actions are perceived, by most actors, as useful to prompt the development of the clean energy niche. However, the discourse analysis has shown some hurdles in the deployment of these technologies in the Boston area, which are reflected in the third storyline.

STORYLINE 3*: "…adoption and diffusion of clean energy technologies in the Boston area are limited by incumbent regime barriers.*"

This storyline is a summary of the comments made by the interviewees in response to the concluding question: "*What do you think is the level of diffusion of clean energy technologies used by companies and households with respect to the achievements of the research in this field?*"

According to most of the interviewees, the Boston area is at an early stage in the adoption of clean energy technologies.

"*Different cities engage differently on environmental protection. In Boston there is Greenovate, a community-driven movement, which works on promoting bike sharing and solar panels, not necessarily clean technologies for companies. There is a drive from the local community. Differently in Cambridge where the industries, the universities (Harvard and MIT) and the municipality work together for greener spaces. Companies and households around Boston don't reach disruptive technologies easily. In fact, as far as chemicals and technologies are concerned, there is a lot of State purchasing and procurement*", stated the interviewees of OTA. In addition, the Harvard University technology officer declared that "*most of what we file is not commercialized; only 30-50% of the patents are commercialized*".

The interviewees give several reasons for the delays in clean energy technologies adoption.

One interviewee from OTA explained that "[*T*]*here is lack of regulations. People don't change unless they are forced to*". In the TUR Act, "*no company is required to implement any specific technology (…) or to reduce or eliminate their chemical use*", he added. The interviewees from the regime institutions also accept the presence of obstacles in building long-lasting public connections with the economy: "[*I*]*n the US we are good in funding enterprises, especially small businesses, but we don't do evaluation at all, we don't build regular relationships and long-term plans with our clusters*", highlighted one of the EPA interviewee.

The technology officer of MIT explains this slow evolution with the political turnover: "*the incentives to the clean energy sector depend on the governing party and there is a mismatch between the horizon of clean energy development and the horizon of politics' turnover. This mismatch is not attractive for venture capitalists at all*". Although venture capitalists are one of the key factors for the flourishing innovation activities of the private sector in the US, they are not particularly attracted to and active in the clean energy market (Mazzucato, 2015) because of its risky character. This problem is also raised by the interviewees from EPA who stated that: "[*E*]*xcept California, other parts of the country are more conservative in terms of venture capital because it takes a long time; particularly, the implementation of clean energy technologies is not something that can happen in a couple of years*". This is one of the reasons why companies "*are afraid of the costs and they don't make business investment on new technologies that they are not sure are going to work out in the long-term*", stated the OTA interviewees.

This storyline is rightly based on the assumption that clean energy technologies are based on radical innovation; consequently, the potential economic and social returns of opening up new business segments and markets within the clean energy sector would outweigh the costs of support. For this reason, such radical change requires significant public support, particularly at the initial phases of R&D processes, in a way which would foster new technology-based firms. Indeed, lack of resources emerged as an "issue" in the interview with the Northeastern University's technology officer who stated that "[*T*]*here is gap of funding in entrepreneurial activity*". However, this concern is also acknowledged by public offices, as one of the interviewees of OTA mentioned that "*15 years ago there was a program called the Strategic Technology Environmental Partnership (STEP). Its purpose was to take new clean technologies and make the proof-of-concept for commercialization. Once the technology was ready to be deployed we proposed it to the companies. The program no longer exists, mainly because of lack of resources and change of administration*".

As highlighted by the interviews, the lack of venture capital investments and their decrease in recent years against the increase of clean energy technologies has unveiled several gaps in the public support for these technologies. Indeed, the withdrawal of venture capital activities from the scene has significantly affected the emergence of our third storyline, which substantially undermines the belief that the Boston area has embarked on a flourishing path to a clean technology transition.

All in all, storylines 2 and 3 seem to confirm what emerged in storyline 1; i.e. the clean energy niche in the Boston area has reached a commendable maturity level, and is potentially ready to break through the incumbent regime. However, these two storylines substantiate the maturity achievement from two rather contrasting perspectives. On the one hand, storyline 2 stresses the importance of public policy support in the niche maturation process. On the other hand, storyline 3 suggests that not only policy intervention has not supported the clean technologies niche sufficiently, but that it has rather hindered its empowerment considering the lack of effective policy measures.

For the sake of clarity, we summarize the key conflicting narratives that emerged along the second and the third storylines in Table 2.3.

Tab. 2.4 Framing the conflict between storylines [*S2*] and [*S3*]

Legitimizing Public Engagement	Key Narratives		Key Narratives	Delegitimizing Public Engagement
[*S2*] "***Public intervention is everywhere…***"	The adoption of environmentally friendly laws by the government of Massachusetts has been significant, accounting for a large number of laws and regulations concerning air quality, toxic and hazardous waste, recycling and water resources.	=> <=	Absence and lack of harmonized regulations.	[*S3*] "***…adoption and diffusion of clean energy technologies in the Boston area are limited by incumbent regime barriers.***"
	All levels of government have designated funds for the implementation of programmes for the transition to clean energy technologies.	=> <=	Lack of resources since clean energy technologies require long-term investment and viewpoint.	
	Public intervention also targets infrastructure and networking.	=> <=	Public facilities for prototype tests are offered occasionally.	

2.5. Discussion and concluding remarks

The necessity and commitment for a transition to sustainable innovation has dominated the discourses of global and local actors, also in the United States where industrial production still depends to a very large extent on non-renewable energy resources. Although decarbonization is about to be completed, it is only one of the drivers for the reduction of pollution in the US (Geels, 2014). This trend is explained mainly with the substitution of coal with natural liquefied gas (NLG), partly because of the relocation of intensive manufacturing industries to developing countries and, to a lesser extent, due to the use of clean energy technologies in the country's economy.

Having in mind this complex scenario, the central research objective of this chapter has been to examine the discourse on the barriers that limit a full deployment of the clean energy niche in the Boston area. Overall, our investigation showed that the clean energy niche in the Boston area is perceived by a vast majority of actors as sufficiently mature to drive a sustainability transition towards a cleaner energy scenario. Moreover, emerging discourses highlighted the presence of pressures exerted upon the incumbent regime from both the landscape level as well as from struggling actors operating within the regime.

Indeed, narratives building the dominant storyline (S1) pointed at niche maturity suggesting that actors at the niche level, together with institutions at the regime and the landscape levels, share common expectations, having the same goals to be achieved for a transition to a cleaner future. Moreover, interviewees declared that they felt part of a dense network of academic institutions, firms, business infrastructures and public agencies, all aiming towards invention and technology transfer.

Having in mind the importance that the literature attributes to policy intervention for the adoption of clean technologies, we further tested the engagement of public agencies in the Boston area. As a consequence, we identified a legitimizing public engagement storyline (S2) that claims that the public policy intervention has been crucial for the niche development by means of different programmes and funding schemes, providing research and grants to start-ups, supporting workforce qualification programmes and building business development infrastructures within a rather clear legislation framework for environmental protection.

However, the narratives fitting the public delegitimizing storyline (S3) identified gaps at the policy level concerning absence and lack of harmonized regulation, lack of resources, and occasionally offered infrastructure (e.g. facilities for prototype tests), which, according to the respondents, delay the use of clean energy technologies in the Boston area. These gaps have emerged as a consequence of two major pitfalls of the public strategy in support of the clean energy niche: (1) policy intervention has not yet succeeded in building an effective commercialization programme – this has embodied lack of harmonized regulation and of facilities for prototype tests, creating a situation in which these technologies are hardly actually adopted in the Boston area; (2) policy intervention has not yet fully succeeded in crowding-in private investments into the clean energy sector concerning lack of resources for long-term research and investments.

All in all, the internal struggling elements of the regime supporting storyline 3 (S3) that delegitimize public engagement show elements of destabilisation at the regime level. However, until landscape shocks will not generate discursive shared narratives, the Boston area emerging clean energy niche, though significantly mature, will not succeeded in overturning the incumbent regime. This explains why, although the government has invested significantly in clean technologies research and development, it has fallen short in two respects – building an effective commercialization programme and crowding-in private investments into the clean energy sector.

As a final remark, we shall suggest a possible action to overcome these pitfalls and speed up the transition process. As noted the clean energy sector in the Boston area is largely composed of small companies, especially start-ups, which are dispersed state-wide. This industrial structure struggles to develop and as such is not attractive for venture capital investment, which are "focused on some of the safer bets rather than on the radical innovation that is required to allow the sector to transform society so as to meet the double objective of promoting economic growth and mitigating climate change" (Mazzucato, 2015: 136). Therefore, larger amounts of public resources need to be invested to stimulate growth of such small companies, this in turn, would crowd-in private investments facilitating a fruitful entrepreneurial environment and stimulating the development of dedicated infrastructures for the deployment of innovative clean technologies.

Chapter 3

Spatial perspectives on niche empowerment: an agent based model

Socio-technical transition studies are gaining momentum, hence new debates from correlated areas of research are important in enriching and better defining this theoretical framework. Among others, contributions from economic geography have developed the concept of a local-global niche, trying to answer questions like where do technological niches emerge and why and how it occurs in some places and not in others (Raven et al., 2012; Boschma et al., 2017). This study wishes to go beyond the understanding of the driving forces of niche emergence in a specific geographical area. Based on the findings outlined in Chapter 2, this chapter aims at understanding how the local networking and the trans-local influence the maturity of a niche, establishing itself either as a global niche or as a local niche able to break through the incumbent regime. Its purpose stands in the identification of the dynamics that boost some niches to mature rapidly, while some others slowly undermining their ability to overcome the incumbent regime. In order to achieve this goal, we develop an agent-based model (ABM), which allows us to investigate the abovementioned dynamics through the interactions and behaviours of heterogeneous agents within and beyond the niche. By adopting an agent-based modelling we wish to engage with another emerging debate in transition studies which deals with the challenges of using models for analysing these dynamics (Holtz et al., 2015; McDowall and Geels, 2017). Since there have been several contributions (see among others Coenen et al., 2012; Raven et al., 2012; Truffer et al., 2015; Hansen and Coenen, 2015) trying to understand the spatial role in socio-technical transitions without achieving a common theorisation, we accept the challenge of modelling in order to systematise and allow a clearer comprehension of this new spatial aspects in transition studies. However, being aware of the complexity in dynamic frameworks such as transition, we will try to keep it complex (Stirling, 2010). The ABM developed hereafter will account for the emergence of two types of niches with local and global networks, respectively. These two baseline models will then be compared against a mixed network where local ties emerge along with global once. The discussion will further proceed introducing a policy scenario where the technological development within the niche is promoted through knowledge creation – e.g. through public investments in R&D. In the following Section, we review the existing literature about geographical dimensions in transition studies. We then describe the characteristics and behaviour rules of agents within the agent-based model in Section 3.2. In Section 3.3, we report the results of the simulations. Finally, in Section 3.4 we present discussion and conclusions.

3.1. Geographical dimension in transition studies

Innovation processes do not follow linear paths but, rather, are determined by: (1) local capacity building and knowledge creation processes, generated by a systemic interplay between academia, industry, and government (Etzkowitz and Leydesdorff, 1997; Iammarino, 2005); and (2) external pressures and circumstances determined by global production chains and international technology transfer. Indeed, successful long-term innovativeness depends largely on the ability to trigger a combination of dense local ties and extended extra-regional connections (Bergek et al., 2008). Therefore, since innovation is a territorially-embedded process, the geographical scale should always be considered as part of the innovation process.

3.1.1. Strategic Niche Management in sustainability transition

Innovation is about new technologies, but also about socio-economic and cultural changes, which on the one hand boost the development of innovative technologies, and on the other hand, are shaped by them. Hence, from the development of a new technology to its market uptake (which necessarily involves its socio-economic acceptance), long time span and the interaction of territorially endogenous elements and actors, are often required. This issue becomes critical particularly for sustainability innovations regarding the production of energy, transportation, water and agriculture, which directly compete with saturated markets of conventional technologies. The journey from the laboratories to the market can be facilitated by the emergency and creation of technological niches (Schot and Geels, 2008), which are protected spaces where experimentation and supportive socio-technical networks emerge (Smith and Raven, 2012). Technological niches are protected space because it is where the trial and error processes take place in order to improve the performances of new technologies and enables innovations to enter broader and stable markets. While the niche emerges as a protective space, it then empowers and becomes essential for the development of path-breaking innovations that become more competitive and able to overtake the incumbent socio-technical regime, thus promoting a socio-technical transition towards more sustainable patterns.

As explained in section 1.2, the mechanisms which empower the technological niche to break through the incumbent regime has been developed by the Strategic Niche Management framework. According to this theoretical background, there are three mechanisms that should be manifested within the niche and among niche actors, and their coexistence and intensity determines the niche's maturity toward sustainability transition. For this reason, in this study we have modelled actors' characteristics based on these three mechanisms:

i) Converging expectations toward a common and shared view among actors determines the readiness of those actors to adopt the niche technology. This mechanism is important because it overcomes the initial uncertainties and lack of confidence, it attracts the attention of a high number of actors, boost actors to invest in the new technology, and determines the trend of the learning process (Schot and Geels, 2008);

ii) The process of network building establishes a community of actors who have high expectations about the niche technology and who are willing to invest in the development and knowledge sharing about the new technology. At the same time, the presence of a dense network influences the future expectations, and the links between actors increase the knowledge among the network actors about the niche technology. Moreover, the networking process becomes crucial when it involves powerful actors who bring additional resources to the network, i.e. financial, infrastructural, knowledge.

iii) Knowledge about the niche technology covers several features of the learning processes, i.e. technical, socio-economic, policy and regulation, environmental, cultural, and users' preferences. The presence of learning processes is very important for generating an adequate amount of knowledge that influences actors' expectations; more information the actor has about the new technology, less uncertainties she/he faces, easier it is for the actor to interact with other actors, thus for the niche to become mature. Building relations with other actors who share the same expectations is important in terms of increasing knowledge; actors increase knowledge individually through the process of learning by doing, as well as through the process of learning by interacting (Lopolito et al., 2011). The latter is crucial for sharing informal, tacit, and uncodified knowledge which is particularly the case of new technologies in emerging niches.

The occurrence of these three mechanisms is determined by endogenous drivers, enacted collectively, and ranging from the capability of some actors to anticipate future technologies and influence future selection processes, to the occurrence of specific learning processes and their relation to social, institutional, and cultural characteristics.

3.1.2. Spatial aspects in innovative production systems

Innovation and technological development are not limited to the firm level, but firms are part of a global production network (Gosens et al., 2015) from which they are influenced and where they benefit from and contribute to the innovation process. Firms adapt and reorganize their goals based on their market opportunities (Hall and Soskice, 2001), thus the presence of complementary effects between local assets (i.e. infrastructures, institutions, knowledge, social and non-social resources) and trans-local demand, generates geographical asymmetries in both development and deployment of innovation (Coenen et al., 2012).

While local assets promote co-location of actors and the emergency of local networks, the trans-local connections can be explained by an extended concept of proximity according to Boschma (2005). The geographical proximity between firms and other actors encourages relations and networking which are a key issue for learning and sharing to take place. Nonetheless, geographical proximity is not sufficient to justify linkages between actors and it is neither necessary as a precondition for learning and innovation, but there is also the requirement for cognitive, organizational, social, and institutional proximity (Boschma, 2005). The concept of proximity composed of five dimensions facilitates coordination and trust, thus sharing of information, knowledge and values beyond the geographical distance of actors. Actually, formal and informal networks (Musiolik et al., 2012), as well as local and trans-local networks (Bathelt et al., 2004), are crucial for maturation and diffusion of innovation.

Against this framework, we cannot continue ignoring the multi-scalar networks in socio-technical transition studies, which are complex and multi-level processes influenced by different dimensions at all levels – niche level, regime level and landscape level (Smith et al., 2014). Therefore, in this chapter we aim to restore the spatial sensitivity in the multi-level perspective (MLP) framework, in order to analyse transition as an interdependent process between territorialized, local and trans-local networks within the context of multi-scalar institutional structures. In line with Raven et al. (2012), in this study we confute the definition of niches as geographically bounded and spatially localized, in order to explain how small innovative niches actually benefit both from local and global ties, as drive to maturity. To this aim, we start from a geographical bounded niche with the purpose of showing how territorially exogenous factors affect the local innovation activity generating different socio-technical transition effects.

3.1.3. The suitability of agent-based models

As mentioned above, transition processes are complex, thus it is difficult to apply traditional computational methods to describe them. On the one hand, precisely because of its complexity there are some scholars claiming no reason for modelling transition at all (McDowall and Geels, 2017) and that empirical case studies must be used to describe this process realization. On the other hand, there is the need to systematise the framework of transition process in order to produce tools for actors who want to shape transition paths in presence of mature niches. To account for both points we shall develop an agents-based model, which can catch high inner degrees of complexity. The technological niche is a complex system characterized by goal-oriented units that interact with each other shaping system's properties. Indeed, this dynamic is clearly reflected in ABM which models the individual behaviour and the interactions of the individuals generate the behaviour of the system. Based on their behavioural decisions we can determine the system's evolution patterns.

3.2. The Agent-Based Model

As mentioned above, we will apply an agent-based model in order to theorize the spatial-sensitivity in transition studies. Extending the model first developed by Lopolito et al. (2013), we will introduce the spatial aspects in the SNM dynamics in order to understand how the geographical dimension of ties among actors encourage niches to become either local or global players and how this dimension impacts on their capability of destabilisation and breakthrough of the incumbent regime.

In the following sub-sections, we provide a description of the general dynamics occurring within the niche and external to it, focusing particularly on the three niche mechanisms – i.e. knowledge, expectations, and networking – in order to explain their representation in the ABM.

3.2.1. Framing environment characteristics

The niche is composed by a finite number of firms (agents) $\mathrm{I} = \{1, 2, 3, \dots, N\}, N \ll \infty$, who represent potential innovators. Firms use a specific incumbent technology in their production process but consider innovating – i.e. switching to the niche technology. These agents are profit-seeking, bounded rationale, and operate in a complex and risky environment – due to innovations' characteristic of uncertain success. We assume that agents do not know in advance the outcome of the innovation process, since they do not have full information on the probability distribution of risky events. Another important assumption in this model is that there is just one alternative innovation to the incumbent technology, which is developed at initialisation of the simulation and it is available to all agents. Firms periodically compare the incumbent technology (*regime technology*) to the new technology (*niche technology*) in order to decide whether to switch to the niche technology or keep using the regime technology. Any time a firm switch to the niche technology is labelled as *switcher*.

The initial condition we impose is that firms use the regime technology to produce a generic good under perfect competition, in which every firm has profits equal to 0:

$$\Pi_{i,t} = R_{i,t} - C_{i,t} = 0 \qquad [1]$$

where $R_{i,t}$ and $C_{i,t}$ are respectively firm *i* revenues and costs associated with production at time t. Time is discrete and the generic time-step is denoted by $t = 0, 1, 2, \dots, T$. The firm will innovate if the profit associated to the niche technology is greater than 0. Profits associated to the niche technology depend on revenues and costs, and are defined as follows:

$$\Pi_{i,t}^{n} = \begin{cases} R_{i,t}^{n} - C_{i,t}^{n} & with\ probability\ p \\ 0.5R_{i,t}^{n} - C_{i,t}^{n} & with\ probability\ 1-p \end{cases} \quad [2]$$

where $R_{i,t}^{n}$ is the niche technology revenue that varies across firms and over time. $C_{i,t}^{n}$ is the niche technology cost for firm *i* at time *t*, and *p* is the probability (set, at the initialisation phase, equal to 0.5) that firm *i* will obtain at time *t* the highest profit. This probability captures the risk associated with production under the niche option, which stems from the lack of knowledge on the new technology. Differently from Lopolito et al. (2013), who located firms in a social space, in this model we locate firms in a geographical space. Hence, the population of N firms is located in a geographic environment consisting of a grid of cells. Not all the cells of the grid are occupied by agents, and those occupied are occupied by only one agent. Each agent is initially assigned a random position in the grid, and decides with whom to interact based on its degree of proximity defined both as geographical and relational proximity (we shall come back on this in section 3.2.3).

The geographical space of interaction *S* is specified as a wrapped grid (i.e. a torus) so that there are no edge effects – where we might have different behaviour due to the boundaries of the grid (peripheral agents have smaller neighbourhoods: hence fewer neighbours and fewer opportunities to interact).

Any time two firms using the niche technology interact, they will establish a tie (i.e. a durable link) increasing their expectations on the niche technology success. The reiteration of interactions and the stabilisation of such ties will connect a growing number of actors over time and space. Hence, a network of relations among actors will emerge: this network is defined as the *innovation niche*.

3.2.2. Knowledge and power

Each firm has an attribute called individual power $\left(I_{i,t}^{P}\right)$. At initialisation phase it is set at a specific value describing the firms' endowment of strategic resources. Any time a switcher (i.e. a firm producing under the niche option) obtains an extra profit, it increases its individual power as this extra profit is added to its pool of resources; likewise, individual power will decrease if the profit turns to be negative $\left(I_{i,t+1}^{P} = I_{i,t}^{P} + \Pi_{i,t}\right)$.

Knowledge about the niche technology is defined as a scalar $\left(K_{i,t}\right)$ and is randomly assigned to agents at initialisation. Agents can increase their knowledge on the niche technology according to the following two channels: (i) whenever a firm start producing using the niche technology, knowledge increases through *learn by doing*; (ii) each time a firm interacts with other neighbouring firms, knowledge increases through *learning by interacting*. The latter is composed of learning by interacting locally (i.e. with geographically proximate forms) or learning by interacting globally (i.e. with relational proximate forms). Therefore, we shall define the following knowledge accumulation faction:

$$\mathrm{K}_{i,t+1} = K_{i,t} + \beta_1 L^{n} + \beta_2 (L^{G} + L^{N}) \quad [3]$$

Where β_1 and β_2 are positive parameters expressing respectively the strength of learning by doing and learning by interacting, which are set at initialisation and can vary between 0 and 1; $L^n_{i,t}$, L^G and L^N are the three learning functions. Learning by doing is defined as a positive linear function of individual knowledge, whereas learning by interacting (both globally and locally) is defined as a positive linear function of the size of the *network* (i.e. *the innovation niche*).

As in Lopolito et al. (2013), any time the overall level of firms' knowledge on the niche technology increases, the probability p of obtaining the high profit $\Pi^n_{i,t} = R^n_{i,t} - C^n_{i,t}$ increases. This is because, overall, as agents become more knowledgeable on the niche technology, the risk associated with the production involving such new technology decreases. This is a system feature that affects also firms currently not involved in the niche option; in fact, if they do switch to the niche option they will get $R^n_{i,t}$ with a higher probability. As in Lopolito et al. (2013), we assume that the probability p increases in a linear fashion.

3.2.3. Networking

As mentioned above, every time-step all firms producing with the niche technology (i.e. switchers) get the opportunity to find a partner among neighbouring firms. For the sake of simplicity, the neighbour of each switchers is defined as the entire *S*. Among its neighbours, each switcher establishing a link with the most proximate with whom is not linked.

As already discussed, in the model the proximity among two firms is conceived in both geographical and relational terms. Hence, geographical proximity is defined as the geographical distance between any dyad of firms, whereas relational proximity is defined as the relational distance between any dyad of firms. More specifically, this latter type of proximity captures Boschma's (2005) multidimensional proximity including in our model distance in knowledge, individual power and expectations[9] among actors.

Each switcher *i* calculates its geographical proximity with switcher *j* as:

$$gP_{i,j} = 1 - \frac{D_{i,j}}{maxD} \ with\ i \neq j, i\ and\ j\ \in S \qquad [4]$$

where $D_{i,j}$ is the geographical distance between switchers *i* and *j* measured as the numbers of grid-cells dividing them, and $maxD$ is the maximum geographical distance among all dyads of actors in *S*.

Each switcher *i* calculates its relational proximity with switcher *j* as:

$$rP_{i,j,t} = \frac{min(K_{i,t};K_{j,t}) + min(I^P_{i,t};I^P_{j,t}) + min(ex^n_{i,t};ex^n_{j,t})}{(K_{max} + I^P_{max} + ex_{max})} \ with\ i \neq j, i\ and\ j \in S \qquad [5]$$

[9] Expectations will be defined in section 3.2.4.

where $min(K_{i,t}\,; K_{j,t})$ is the minimum knowledge level of the switchers *i* and *j* at time *t*, $min\left(I^P_{i,t_i}; I^P_{i,t_j}\right)$ is the minimum individual power level of the switchers *i* and *j* at time *t,* $min(ex^n_{i,t}; ex^n_{j,t})$ is the minimum expectation level of the switchers *i* and *j* at time *t*, and $(K_{max} + I^P_{max} + ex_{max})$ is the sum of the maximum possible value reachable by the parameters knowledge, individual power and expectation. Note that while geographical proximity does not vary over time (since firms do not move in the geographical space), relational proximity can vary over time.

At each time step switcher *i* can select either the partner with the highest geographical proximity $max(gP_{i,j})$ or the one with the highest relational proximity $max(rP_{i,j,t})$. Hence, establishing a tie with its most proximate neighbour, that is the switcher with whom *i* is not already linked and that reports either the maximum geographical proximity or the maximum relational proximity. Through this searching mechanism we will be able to construct purely local networks, purely global networks, as well as mixed local-global networks.

As more links are established a *network of switchers* (i.e. the innovation niche) will emerge. This network is characterised by two features: the *network knowledge* (N^K_t) and the *network power* (N^P_t). Following Lopolito et al. (2013) we shall define these two features in the following way:

Network Knowledge – Each time two switchers establish a tie, the total amount of their respective knowledge flows through this tie. Thus, each tie has a feature called tie knowledge ($\Delta_{i,j}$), which is the sum of the knowledge of the agents on either end of the tie:

$$\forall\, \mathrm{i,j} \in \mathrm{N}, \exists\, \Delta_{i,j} \geq 0 : \; \Delta_{i,j} = \begin{cases} K_{i,t} + K_{j,t} \quad if\ i\ and\ j\ are\ linked \\ \quad 0\ if\ i\ and\ j\ are\ not\ linked \end{cases} \tag{6}$$

The total sum of tie knowledge represents, in turn, the overall network knowledge defined as follows:

$$N^K_t = \textstyle\sum_{i,j} \Delta_{i,j}\ \ with\ i \neq j \tag{7}$$

Network Power – Each time two switchers establish a tie, the total amount of their respective power flows through this tie. Thus, each tie has a feature called tie power ($\Gamma_{i,j}$), which is the sum of the power of the agents on either end of the tie:

$$\forall\, \mathrm{i,j} \in \mathrm{N}, \exists\, \Gamma_{i,j} \geq 0 : \; \Gamma_{i,j} = \begin{cases} I^P_{i,t} + I^P_{j,t} \quad if\ i\ and\ j\ are\ linked \\ \quad 0\ if\ i\ and\ j\ are\ not\ linked \end{cases} \tag{8}$$

The total sum of tie power represents, in turn, the overall network power defined as follows:

$$N_t^P = \sum_{i,j} \Gamma_{i,j} \ \ with\ i \neq j \quad [9]$$

Following Lopolito et al. (2013) we shall assume that network characteristics and composition are crucial in defining the particular set-up of experiments. This is due to the fact that no single actor has sufficient resources on its own to coordinate the experimentation activity and this makes them dependent upon each other for crucial resources (Smith et al., 2005). As the network grows, such resources become available for R&D activities.

In the model, this is represented by the fact that both individual and network power have an impact on the cost structure faced by switchers engaged in experimental activities. On the one hand, we assume that increasing individual power will allow switchers to make cost reductions (e.g. by investing extra profits in R&D, firms could introduce process innovations). On the other hand, as the network power increases, switchers will have access to a growing amount of external resources. In other words, we maintain that resources accumulated by other firms can be exploited by means of spillovers within the emerging social network. Hence, we have:

$$C_{i,t+1}^n = C_{i,t}^n - cI_{i,t}^P - nN_t^P \quad with\ c \in [0,1];\ n \in [0,1]\ and\ c \gg n \quad [10]$$

At the same time, we shall assume that as network knowledge grows revenue of firms increases since reputation of the network increases and they attract more agents and expand their markets. Specifically, we have:

$$R_{i,t+1}^n = R_{i,t}^n + \tau N_t^K \quad with\ \tau \in [0,1]$$

Finally, tie power ($\Gamma_{i,j}$) and tie knowledge ($\Delta_{i,j}$) determine the strength of the relation established among dyads within the innovation niche. Specifically, all links created within an innovation niche are subjected to a decay law – that is the link between any two switchers *i* and *j* dies if the level of risk of one or both agents (i.e. one minus the probability *p* of obtaining the high profit) is higher than the sum of tie power and tie knowledge:

$$1 - \mathrm{p} > \Gamma_{i,j} + \Delta_{i,j}\ .$$

3.2.4. Expectations

Each firm is characterised by a level of expectation $ex_{i,t}^n$ that is defined as the preference of firm *i* at time *t* towards the niche technology. The value of expectation varies from 0 (if the agent does not have preferences for the niche technology) to 1 (if the agent has a complete preference for the niche technology) and, therefore, unless expectations are at the maximum, firms tend to underestimate the potential revenue attached to the niche technology. At initialisation, expectations are assigned randomly to firms. Expectations of firm *i* on the new technology increase together with profits in a linear fashion – i.e. any time a firm experience an extra-profit its expectation will increase. In fact, following Lopolito et al. (2013), we assume that the level of expectation of firm *i* at time *t* influences positively the expected cost (reducing it) and the expected revenue (increasing it) of the new technology, as shown in equations (11) and (12):

$$E\left(\mathrm{C}_{i,t}^{n}\right) = \frac{1}{ex_{i,t}}\, C_{i,t}^{n} \qquad [11]$$

$$E\left(\mathrm{R}_{i,t}^{n}\right) = ex_{i,t}\mathrm{R}_{i,t}^{n} \qquad [12]$$

where $\mathrm{C}_{i,t}^{n}$ and $\mathrm{R}_{i,t}^{n}$ are the same as above.

The higher is the expectation, the more likely it is that the firm will switch to the new technology. In fact, firms will switch technology any time the following is satisfied: $E\left(\Pi_{i,t}^{n}\right) = E\left(R_{i,t}^{n}\right) - E\left(C_{i,t}^{n}\right) > 0$

3.2.5. Behavioural rules and firms' decision processes

Each firm undertakes two fundamental decisions every time-step: (1) deciding the technology to be adopted choosing between the regime technology and the niche technology; (2) choosing its partner based on their maximum geographical proximity or relational proximity, building respectively a global network or a local network. As we mentioned above, firms are profit-seeking with bounded rationality; therefore, both choices will be taken comparing expected profits across alternative choices. Note that the default option is using the regime technology and network with local partners. While the decisions to switch technology is irreversible, links created with other agents can disappear in the timeframe of the simulation. However, once a firm has chosen a local or global partner that does not mean that she cannot expand her network and reach also the global or the local one respectively.

All model parameters at initialisation phase are summarised in Table 3.1 below:

Tab. 3.1 Parameters summary

Parameter	Value	Description
$\boldsymbol{K_{t=0}}$	random 0.01	Initial level of knowledge on the niche technology assigned to each firm
$\boldsymbol{\beta_1}$	0.025	Rate at which knowledge increases as firms learn by doing
$\boldsymbol{\beta_2}$	0.03	Rate at which knowledge increases as firms learn by interacting
$\boldsymbol{\tau}$	0.01	Rate at which the risk associated with niche production decreases as the knowledge in the system increases
$\boldsymbol{I_{t=0}^{P}}$	random [0-0.3]	Initial power endowment assigned to each firm
c	0.01	Rate at which production cost is reduced as individual power increases
n	0.01	Rate at which production cost is reduced as network power increases
$\boldsymbol{ex_{t=0}}$	0.5	Initial level of expectations assigned to each firm
$\boldsymbol{R_{\ t=0}}$	1.5	Revenue for firms producing with the niche technology
$\boldsymbol{C_{\ t=0}}$	0.5	Initial costs for firms producing with the niche technology
maxlinks	10 + random [0-1]	Maximum number of ties any firm can create

3.3. Policy tool and simulation results

The model described above was implemented with NetLogo 5.2 platform and the statistical computing and graphics has been elaborated with excel workbook. Since the model includes several random elements, thus not deterministic, repeated simulation batch of 100 runs have been performed to identify a behaviour trend of the model and to guarantee strong results. The batch has the same set of initial conditions except for the random seed that determines the random behaviours of agents, i.e. uncertainty, initial location, etc. To eliminate the random aspects of initialisation, we have calculated average values of all relevant variables within the batch.

In the baseline model agents are assigned a fixed low level of knowledge (see Table 3.1 for parametrisation) at initialisation, the timeframe of the simulations is 500 time-steps and agents can only have local ties based on geographical proximity. This is an extreme context where agents are limited to a local network, however geographically near actors are more inclined to collaborate with each other at least initially. What emerges from Fig. 3.1a is a rather long latency period needed for agents to start switching technology. Agents start switching after 278 time-steps, however the convergence of all agents to the niche technology is completed within 404 time-step. Thus, once the new technology kicks-in, the niche matures rapidly. Quasi-convergence (with the vast majority of the firms - 95% - switch technology) is obtained in about 70 time-steps (from time-step 292 to time-step 362), hence suggesting the occurrence of a period of rapid adoption sandwiched between a long period of slow take up and a late period of approach to satiation.

We compare this baseline model with another extreme case where agents build their network solely on global ties through relational proximity (see Fig.3.1b). In this context agents start switching much earlier – at the 20th time-step – and the total convergence of agents switching to the niche technology is completed after 230 time-steps. Hence, as it seems, in the global niche agents start switching earlier but it takes a longer timespan for the niche to become mature. Also in the global niche quasi-convergence is obtained in a shorter period of time; however, it is slower than in the local niche needing around 100 time-steps for satiation to occur.

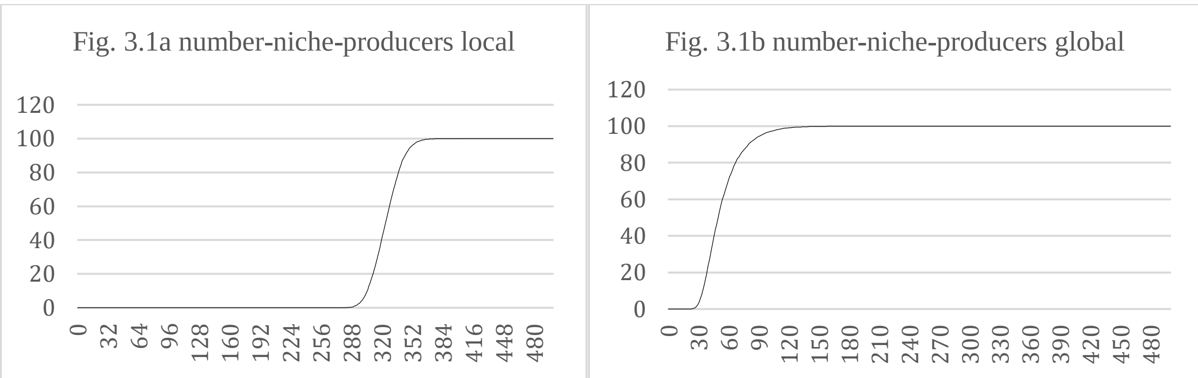


Fig. 3.1 Agents switching to the niche technology in a local niche and in a global niche (low level of knowledge)

The differences in timing and velocity between the local and the global niches can be explained by the characteristics of emerging ties (see Fig. 3.2) that agents create before and while they switch to the niche technology.

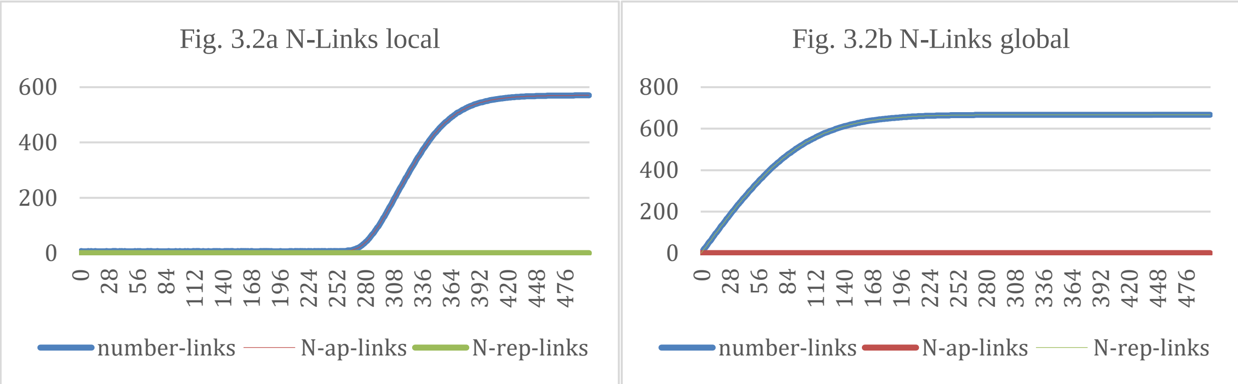


Fig. 3.2 Number of links created in a local niche and in a global niche (low level of knowledge)

In the local niche agents create ties based on their geographical proximity, without taking into consideration knowledge, expectations, or power of their partners; the opposite is true in the global niche case. Hence, the *searching mechanism* to select a partner implemented in the local niche case is somehow more generic, with firms partnering just on the ground of geographical proximity and establishing, therefore, *weak ties*. In fact, as we discussed in section 3.2.3 all links created within an innovation niche are subjected to a decay law and ties can die when the risk in the environment is higher than tie power ($\Gamma_{i,j}$) and tie knowledge ($\Delta_{i,j}$). Therefore, over the latency period local ties are created and die continuously. Reverting the seminal contribution of Granovetter (1973) we could say that in the local niche case, firms experience the "weakness of strong ties" as local connections, though corresponding to a general sense of 'closeness' among firms, are weak in nature as they do not carry similar values in terms of knowledge, power and expectations towards the new technology. To put it simply we could say that the best match is not necessarily the closest one!

Only after the latency period, when expectations, knowledge, and power of the network has overall increased, geographical proximity becomes relevant boosting the diffusion through spillover effects. This explain the fact that in the local niche model it takes so much time for agents to start switching but then they converge fast.

In the global niche model, agents partner based on their relational proximity performing a search centred on knowledge, expectations and power. Therefore, once two agents create a tie, it is more stable than a local tie precisely because tie power and tie knowledge are higher. Consequently expectations, knowledge, and power increase in the network and agents start to switch to the niche technology almost immediately. However, the spillover effects are not so effective as in the local niche case, so the global niche needs a longer timespan to reach saturation.

Against these two extreme cases, we shall now compare a mixed case where firms can establish both local and global links. Result of mixed niche with global-local ties are reported in Fig. 3.3.

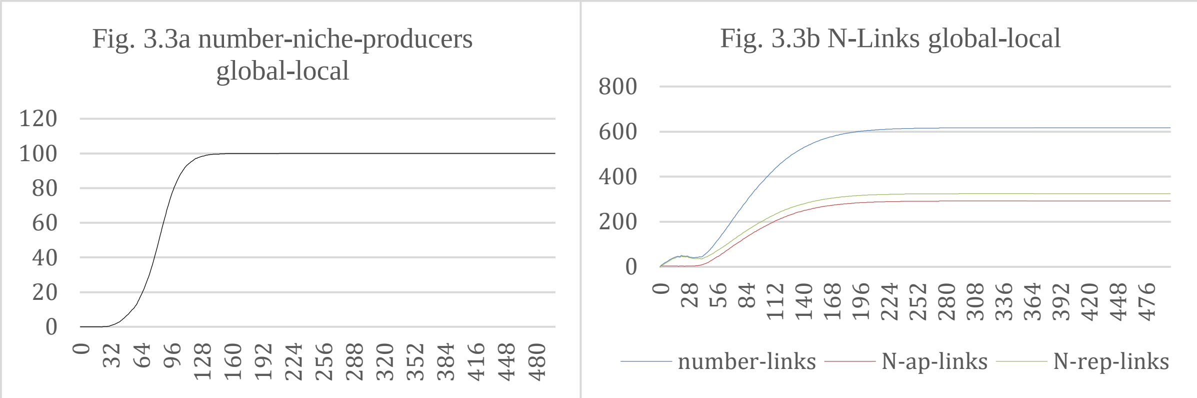


Fig. 3.3 Agents switching to the niche technology and number of links created in the global-local niche (low level of knowledge)

When agents have the possibility to choose their partners based on either their geographical proximity or their relative proximity the niche creation starts early and it matures fast, accounting for both positive properties of the global niche and the local niche respectively. Agents start to switch much earlier than in the local niche (but a few time-steps later than in the global niche, at time-step 22) and they converge much later than the local niche (but earlier than the global niche, at time-step 210). Interestingly enough, this mixed case bears positive elements stemming from the global niche model (in terms of strength of ties) as well as positive elements stemming from the local niche model (in terms of spillover effects). Hence, convergence kicks in relatively soon and is generally fast. As Scott (1988) indicates, the performance of a localized production system depends on the right mix of local and trans-local exchanges.

As a final exercise, we shall now investigate what would happen if a policy intervention investing in R&D is implemented, increasing the initial level of knowledge. We shall investigate the impact of a high level of knowledge on timing and speed of convergence in the three types of niches considered above.

As an effect of this policy action, in the local niche the latency period is significantly reduced (see Fig. 3.4) from the 278 time-steps to just 42 time-steps. Moreover, the speed of niche maturity increases from 126 time-steps needed for agents with a low level of knowledge to 78 time-steps for a complete convergence in the high-knowledge case. Quasi-convergence occurs in as little as 48 time-steps.

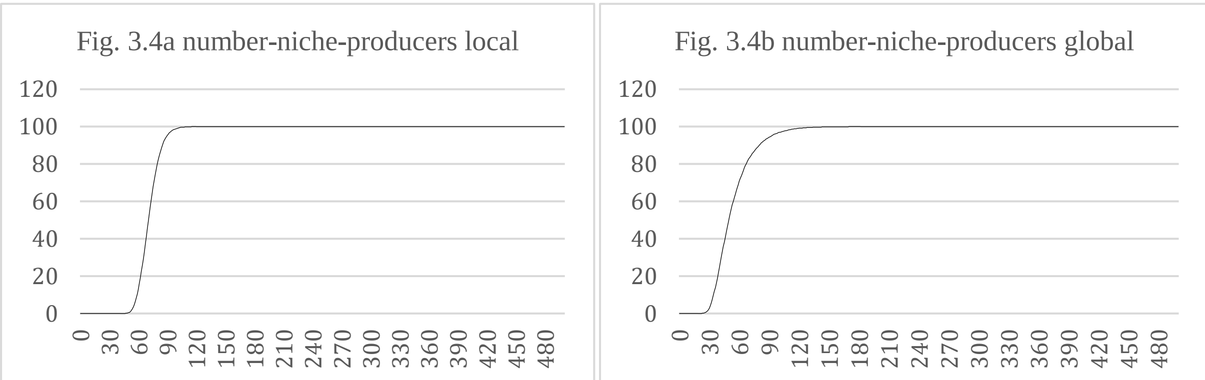


Fig. 3.4 Agents switching to the niche technology in a local niche and in a global niche (high level of knowledge)

A similar pattern occurs for the global niche with a high level of knowledge. The niche emerges immediately (at the 19th time-step), and reaches convergence in 163 time-steps and quasi-convergence in just 91 time-steps.

Also in the high-knowledge case the most interesting results emerge in the mixed global-local niche (see Fig. 3.5). Particularly when agents are initially assigned high level of knowledge, a global-local niche emerges very early, at the 24th time-step, and matures very fast, in 126 time-steps. Quasi-convergence is extremely fast occurring in as little as 63 time-steps.

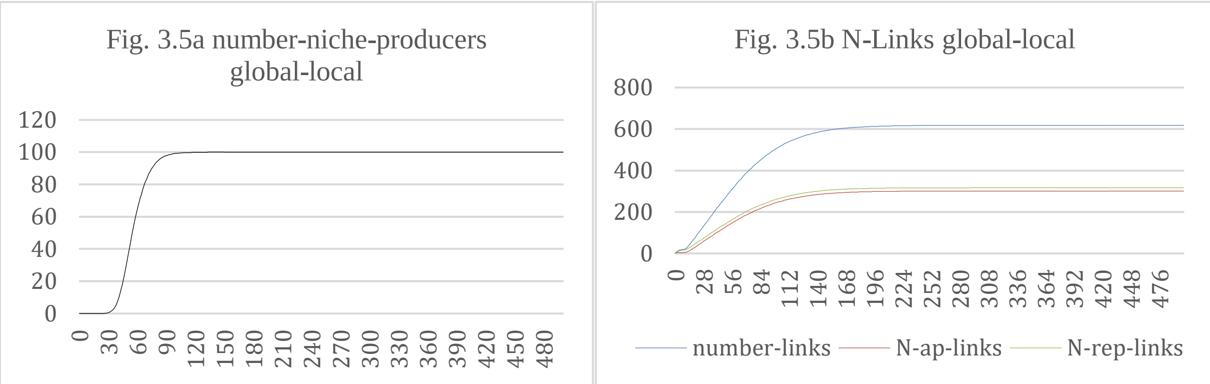


Fig. 3.5 Agents switching to the niche technology and number of links created in the global-local niche (high level of knowledge)

All in all, increasing the initial knowledge level has a positive effect across the three models reducing latency and accelerating convergence. However, the local network model benefits the most from such a policy intervention. This, in turn, would suggest that if firms are unable to link globally (and therefore to be part of an international network), policy makers could speed up the transition process by investing in knowledge and stimulating R&D activities locally.

3.4. Conclusions

In this chapter, we developed an agents-based model aimed at investigating the influence of the spatial dimension of niche agents' network in the niche creation and maturity, and the impact of a policy intervention in order to map the niche agents' behaviour. To this aim, we initially considered agents who create a bounded territorial network, and which are not involved in trans-local relations. This behaviour triggers a local niche which starts to emerge very late but converges very fast. Moreover, the links created among agents initially are characterized by a high instability because grounded only on the geographical proximity.

At the opposite side of the spectrum we simulated a situation where agents can create only long-distance ties based on relational proximity. This a-spatial network generates a global niche which emerges very early, but it matures slowly. In this case, the links among agents, being based on social, cognitive, organizational, and institutional proximity, are more stable than in the local niche.

Finally, when we simulated a close-to-reality situation with agents creating ties based on their geographical proximity as well as their relative proximity, a mixed global-local niche emerged. The global-local niche emerges early, earlier than the local niche, and matures fast, faster than the global niche. Further, we introduced a policy intervention in order to test the niche behaviour under external influences. With a higher level of knowledge (e.g. through public investments in R&D), earlier findings are conformed and reinforced.

These results help enlighten partly the results of Chapter 2. The fact that the clean energy technologies niche in the Boston area emerged quite fast, however its maturity is taking longer, can be explained with the propensity of this niche agents to build more global relations rather than focusing on local networks; delaying the transition process to clean energies.

All in all, our contribution to the vast and fast-growing literature in transition studies stands on introducing a systemized spatial aspect as a fourth mechanism in the Strategic Niche Management framework, in addition to knowledge, networking, and expectations. A mature local niche will react differently to the incumbent regime respectively to a spatially unbounded global niche, generating different outcomes in the transition process.

Chapter 4

The transition towards a bio-based economy: a comparative social network analysis

The global population growth, coupled with current mass production and consumption models are putting under pressure the availability of global resources needed to fuel long-term growth. As pointed out by several scholars and in-depth investigated in section 1.3, current socio-economic challenges demand for a radical change in consumption habits (Spaargaren, 2011; Seyfang, 2009) and in the production system (Maxwell and van der Vorst, 2003) through the development of innovative and sustainable technologies. New technologies could indeed facilitate the transition from a society based on fossil fuel resources, mass consumption and inefficient waste management to one based on renewable resources and biomass, reduced consumption, and reuse-oriented waste management (Morone, 2016).

Against this background, the bio-based economy has gained momentum in the transition literature as one of the primary paths through which this 'change of perspective' will occur. In this chapter we focus particularly on the bioplastics industry, as an important sector of the bio-based economy for two fundamental, and substantially "quantitative", reasons: on the one hand, the consumption of plastics in Europe is considerable, equalling 58 million tonnes annually (Plastics Europe, 2016); on the other hand, the bio-waste generated annually across the EU ranges between 118 and 138 million tonnes [European Commission, 2010]., this representing a sizeable amount of potential feedstock to be used in the production of bio-based products, including bioplastics. (Bayer et al., 2014; Ladu and Quitzow, 2017; Imbert, 2017)

To date research has mainly focused on the technical aspects of bioplastics production, however, there are hardly any studies focusing on pathways of evolution from technological research and innovation to technological bioplastics niches maturation in European countries. Bearing this in mind, and building on Morone et al. (2015), this study provides a comparative assessment of the development of the bioplastics niches in Italy and Germany as they represent two interesting case studies due on one hand, to their strong consumption of plastics, and on the other hand, their high production capacity level of bioplastics. Specifically, relying on the Strategic Niche Management framework the following niche mechanisms are analysed: (1) convergence of expectations of the firms involved in bioplastics production in Italy and Germany, (2) their learning processes through the exchange of informal and formal knowledge and (3) their networking activities with powerful actors in the sector.

This is all more interesting considering that Germany and Italy have implemented divergent policies in support of the bioplastics industry (Imbert et al., 2017). Hence, results obtained on the emerging architectural properties of the two niches will be linked, in a retrospective way, to the different policy strategies enacted by the respective national governments, this under the common umbrella of the EC policy for the bio-based economy. Therefore, the aim of this study is twofold, i.e. to investigate the maturity level of the bioplastics niches in Germany and Italy and its connection with national policies in support of the bio-based economy. In order to accomplish the goals of this study, a combination of qualitative and quantitative tools, including experts' opinion and Social Network Analysis have been applied.

The chapter is structured as follows: Section 4.1 gives an overview of the theoretical background based on strategic niche management and innovation policy. Section 4.2 describes data collection and methods. Section 4.3 frames the case study and presents the results in a comparative way. Section 4.4 links findings to the countries' policy strategies and concludes the chapter.

4.1. Theoretical framework

Bioplastics represents a very promising niche market. However, it faces many challenges related to the dominant position of the incumbent regime – including price competition and social acceptance of new products. Bioplastics, especially those based on waste feedstocks, will benefit from a well-established circular economy model, where actors at all levels are engaged in collaborative networking activities and oftentimes freely share knowledge. Indeed, synergies arising between institutions, research bodies, industry and consumers define the internal forces and the external sources of pressure capable to destabilize the incumbent socio-technical regime (Geels, 2002) based on conventional plastics production. Moving along these lines of reasoning, we adopted a multi-level perspective (MLP), focusing on the three interconnected levels that can determine the success of a radical innovation and a path-breaking socio-technical transition. These are the innovation niche, the regime and the landscape, – whose interactions can either jeopardize or trigger the transition, but which, in any case, shape the formation and empowerment of emerging technologies (Schot, 1992; Rip, 1992). Institutional change and policy intervention are indeed key guiding forces towards the accomplishment of the decarbonisation process, which competes with traditional infrastructures and less expensive products –typically better-known by the market (Hopkins and Lazonick, 2012). For this reason, the outcome of a transition towards a bio-based economy is very much determined by the type of policy strategy implemented and the way it takes form.

In this respect, the framework in Quitzow (2015) provides a list of criteria for the identification of different types of policy strategies, grounded on policy objectives and associated measures (strategy content), policy development, implementation and adaptation (strategy process) and institutional capacities (strategic capacity). Built on Quitzow (2015), Imbert et al. (2017) identified two types of policy strategies in a comparative case study, assessing the emergence of a bio-based economy in Germany and Italy. They pinpointed a bottom-up strategy in Italy, also defined as a demand-side policy, implemented with the law n. 28/2012, which was the result of pressure applied mostly by the private sector. On the other hand, a top-down strategy emerged in the German case, where the policy strategy was implemented by means of considerable public investment in R&D aimed at boosting research and innovation activity, and stimulating, through a supply-side policy, the emerging bio-based German economy. This analysis sets the theoretical ground for analysing how these two alternative policy tools have triggered the creation and development of the bioplastics niche in the two countries under scrutiny.

To analyse the level of maturity and the structure of the network of the bioplastics niche in Italy and Germany we relied on the Strategic Niche Management framework (Kemp et al., 1998). According to this theoretical approach, the maturity of a technological niche is grounded on three crucial mechanisms; i) convergence of expectations towards a common view on the success of radical (and/or incremental) innovations within technological niches for challenging the incumbent regime; ii) learning processes as crucial means for increasing formal and informal knowledge, boosting technology transfer and spreading the use of innovative technologies; iii) networking with powerful actors, which have resources to promote markets and infrastructures for new technologies. All this come down to the belief that "[N]o single actor has sufficient resources on their own to coordinate responses to selection pressures, or build adaptive capacity" (Smith et al., 2005: 1503). The presence or absence of these three mechanisms determines not only the emergence of an innovative niche but also its level of maturity (empowerment) able to break through the incumbent socio-technical regime.

4.2. Empirical Strategy and Methodology

To compare the German and Italian bioplastics niches having in mind convergence of expectations, learning processes and networking activities with powerful actors in the sector, we carried out an investigation by means of both qualitative and quantitative methods, articulated into three main steps.

We started with a stakeholder analysis, reviewing academic and grey literature to identify most relevant actors involved both in the Italian and German bioplastics industry.

As a second step, we developed a questionnaire for the firms involved in the production of bioplastics in Italy and Germany, which was composed by three sections. The first section aimed at collecting general information about the firms involved in the bioplastics industry, with questions on their product specialization and the number of workers hired. By using a five-point Likert scale, the second part of the questionnaire was designed to gather data on firms' expectations on the future development of the bioplastics sector by focusing on current and future technologies and their environmental and economic sustainability. Furthermore, respondents were asked to point at the main challenges associated with the production of bioplastics. Three questions relating to patents, trademarks and R&D funding were also included. Lastly, the third part of the questionnaire collected data on two types of firms' networks: informal knowledge sharing and formal knowledge exchange. Along with sociometrical data, eight questions investigated the presence of powerful actors in the networks.

In the third step of our analysis we coordinated two focus groups of stakeholders (identified in the first step) that assessed the content validity of the questionnaire and provided a list of the five most relevant firms actually involved in the respective domestic markets. Focus groups were conducted respectively in Italian and German and were both composed of four members: a government representative, a research institution representative, an industry representative, and a trade organization representative.

As just mentioned, the final part of the questionnaire specifically targeted the networks analysis since the acquisition of informal and formal knowledge through networks of relationships and the presence of powerful actors are key elements of this investigation (see Imbert et al., 2017; Giuliani and Bell, 2005). The aim of the social network analysis was therefore to develop an ego-network of the firms involved in the bioplastics industry in each country so as to investigate the development of a bioplastics market from an industrial point of view (see Lechner and Dowling, 2003). We applied a Social Network Analysis (Wasserman and Faust, 1994; Scott, 2000) to control for the presence of informal and formal knowledge exchange both among firms and between firms and other external actors – such as Universities and research centres, public administrations, business support organizations and NGOs. Indeed, relationships with this type of actors play an important role in shaping the architectural properties of the emerging networks.

As mentioned, in each country the questionnaire was initially submitted to the five actors suggested by focus groups' participants. Subsequently, this figure was augmented applying a roster-recall method. For each of the firms pre-listed in the roster, the respondent firm had to indicate whether or not it had a relationship of a pre-defined type, distinguishing among informal knowledge and formal knowledge exchange. In addition, respondents were asked to recall all other firms they had this type of relationship with (over the last five years) and add them to the list. Doing so, we compensated for the fact that not all local actors were pre-listed on the roster. On the other hand, relationships with external actors was built by using a pre-ordered category-list of external actors identified through focus groups and augmented through the recall method. Through this methodology, we obtained: (A) for Italy – a network of 30 firms and 30 external actors; (B) for Germany – a network of 24 firms and 63 external actors.

We imported data as an adjacency matrix in Excel format and further imported it into the social network analysis software UCINET 6 (Borgatti et al., 2002), in order to visualize the networks and to calculate the measures most relevant for our analysis (i.e. density[10], inclusiveness[11], clustering coefficient[12], and the network centralisation[13]). The questionnaire was administered online using the Qualtrics platform between March and May 2017.

4.3. Case studies and results

Almost 40% of the 49 million tonnes of European plastic material demand is concentrated in Germany and Italy (PlasticsEurope, 2016), with Germany playing the role of Europe's largest producer of plastic through its leading plastic industry (GTAI, 2016/2017). This contrasts with the fact that both countries are EU bio-based economy frontrunners, ranking 1st and 2nd in terms of turnover and employment, respectively (Piotrowski et al., 2016). In 2016, both countries accounted with a high production capacity for bioplastics/biopolymers, estimated at 109,515 t for Germany and 150,000 t for Italy (European Bioplastic, 2016). Germany and Italy were selected as case studies for the empirical research of this chapter because of the importance of their bioplastics industries and the active but fairly different policy interventions taken by their respective national governments (Imbert et al., 2017).

4.3.1. Convergence of expectations

By analysing information gathered in the first section of the questionnaire, it resulted that the German bioplastics industry is mostly composed of large firms (i.e. with more than 250 employees), while the Italian industry is largely characterized by small- and medium-size enterprises and one leading large firm. Most of the Italian firms that participated in the survey are specialized in the production or commercialization of bio-based shoppers and bioplastic cutlery, whereas in Germany most of the participants are specialized in the production of intermediate bio-based materials and compounds.

[10] Ratio of existing ties to all possible connections.
[11] The number of connected points expressed as a proportion of the total number of points.
[12] A measure of the degree to which actors (vertexes) in a network tend to cluster together.
[13] A network index that measures the degree of dispersion of all node centrality scores in a network from the maximum centrality score obtained in the network.

As shown in Figure 1, bioplastics are expected to gradually replace traditional plastics in both countries and employ production processes that will become economically efficient and environmentally sustainable by 2030. These expectations are slightly higher among Italian respondents. German experts are divided in opinion on whether current technologies allow for the economically efficient production of bioplastics, while Italian experts tend to agree on this. In comparison to Germany, more experts in Italy consider bioplastics production to be already sustainable from an environmental point of view. The higher expectations of Italian firms on the future of the bioplastics sector can be related to the bottom-up and less bureaucratic strategy pointed out in by Imbert et al. 2017 and briefly discussed above.

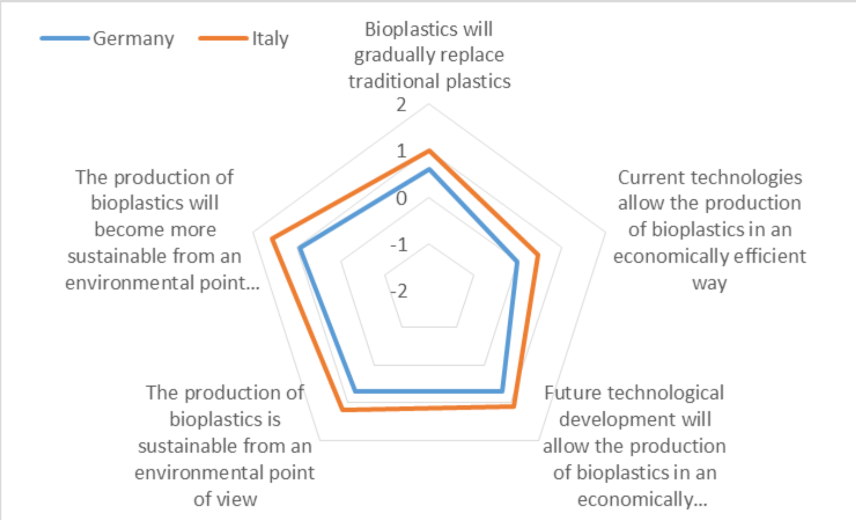


Fig. 4.1 Firms' expectations on the future of the bioplastics sector

In the second part of Section II, respondents were asked to answer questions concerning the main existing challenges (risks and uncertainties) that hamper the development of the bioplastics sector. The positions of interviewed firms in this regard are not as homogenous as they are in the first part of Section I discussed above – differences emerged both within and between countries. Only one-third of the participants, mostly located in Germany, considered the lack of demand for bioplastics and the lack of investments in the industry to be constraints that might hamper the development of the market. Moreover, both countries considered the lack of regulation and long-term supportive policies to be the main challenges hampering the development of the market. Also, the majority of the participants considered the competition from other products and/or firms another factor hampering the development of their markets. On the other hand, the majority of participants did not consider technological constraints to be an existing challenge in the production of bioplastics; also, the majority of firms participating in the survey did not see the lack of a qualified labour force as a challenge. Overall, several challenges emerged in the perception of interviewed firms. However, in both countries none of these challenges was unanimously perceived as extremely severe. Results are summarized in Figure 2.

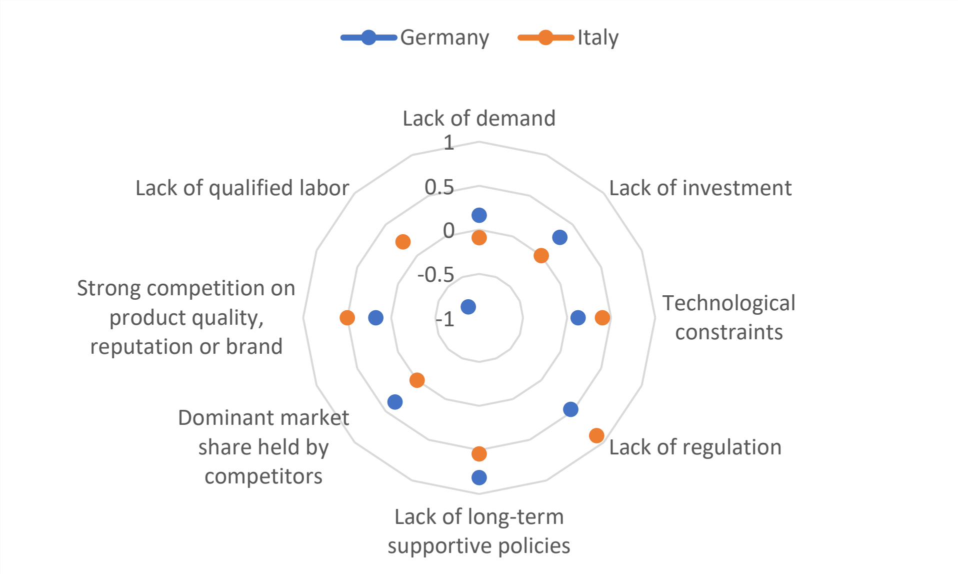


Fig. 4.2 Firms' perception on exiting challenges to the future of the bioplastics sector

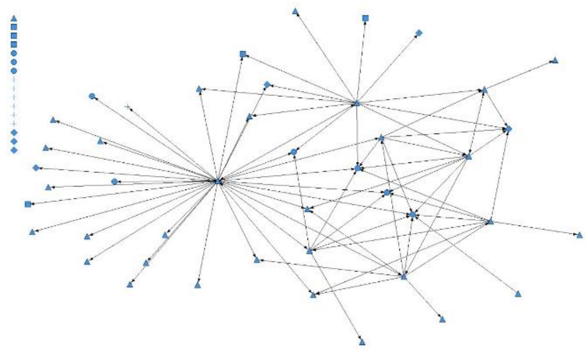
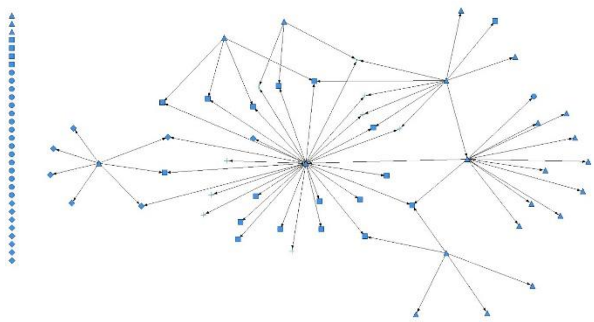
4.3.2. Learning processes

To assess the learning processes, we applied a Social Network Analysis based on the data gathered with the third section of the survey related to two networks for each country – i.e. (1) sharing of informal knowledge, (2) formal knowledge exchange (composed of the development of joint patents, patent licensing, and staff or researchers exchange). One overall outcome of this analysis, which applies both to Italy and Germany, is the density of the two network typologies. The network of informal knowledge share is denser than the formal knowledge exchange network, which actually is disconnected.

4.3.2.1. Informal knowledge share

When looking closely at the informal knowledge network, we can observe the presence of a single component in both cases with few isolated actors, reflecting an inclusiveness degree equal to 73.3% in Italy and to 64.4% in Germany. Moreover, both networks display a large number of peripheral actors connected to few central nodes. This reflects in the generally low density of the two systems, equal to 2.3% in the Italian case and to just 0.9% in the German case, suggesting that firms only take limited advantage of all possible relationships with other firms and external actors for exchanging knowledge.

Comparing Fig. 1a and Fig. 1b, the most striking result emerging with respect to informal knowledge networks is their composition in terms of actors' typologies. In the Italian case, most of the existing links connect firms involved in the production of bioplastics. Few additional links bring into the network a handful of business support organizations, research institutions, and NGOs. The German network is characterized by a much higher participation of public institutions, research institutes and NGOs to the informal knowledge network. The higher heterogeneity of actors' typology in the German niche is also related to the vigorous policy intervention put into place by the German government in terms of public R&D expenditure, thus bringing public actors into the bioplastics niche. This was not the case in Italy, where most of the government initiatives were concentrated on the demand side, boosting the market uptake of bioplastic shoppers (e.g. Morone et al., 2015; Imbert et al., 2017).

Fig. 4.3a Informal knowledge network in the Italian bioplastics industry	**Fig. 4.3b Informal knowledge network in the German bioplastics industry**
	

Note: *Triangles = firms; rectangles = research institutes/universities; plus = public institutions, circles =business support organizations; diamonds = NGOs/associations*

Fig. 4.3 Informal knowledge network in the Italian bioplastics industry and the German bioplastics industry

Also, the clustering coefficient of the Italian informal knowledge network is higher when compared to the German case – the two coefficients equalling respectively 0.401 and 0.008. This property of the two networks stems from their highly centralised structure, which in the German case shows a network relying on just four actors connecting nearly 80% of non-isolated nodes.

Tab. 4.1 Measures of the informal knowledge network

Network	Nr. of ties	Density	Inclusiveness	Clustering coefficient (overall graph)	Network centralisation (OutDegree)
Informal knowledge (IT)	80	2.3 %	73.33%	0.401	51.13%
Informal knowledge (D)	70	0.9%	64.4%	0.008	33.17%

4.3.2.2. Formal knowledge exchange

As mentioned above, the formal knowledge exchange networks are less dense than the informal knowledge networks, equalling 0.8% of density in the Italian bioplastics industry and 0.1% in the German one. Both the Italian and German networks are clustered in two components, however whereas in the German formal knowledge network the principal component includes less than 10% of the total number of actors, in the Italian formal knowledge network the principal component is composed of more than 40% of the total number of actors. Like in the informal knowledge network, in the formal knowledge network in Italy the main actors are firms and some service-providing firms, while in Germany this network is composed of public institutions, as well as research institutes in addition to bioplastics production firms. Since formal knowledge includes three channels through which formal knowledge is exchanged (namely: staff exchange, patent licensing, and patent development), the heterogeneity of actors involved in the German formal knowledge exchange network shows, on the one hand a high mobility of employees from the public to the private sector (and/or vice versa) and from research institutes to private firms (and/or vice versa), and on the other hand a more effective cross-fertilisation of knowledge among public institutions, laboratory research and firms.

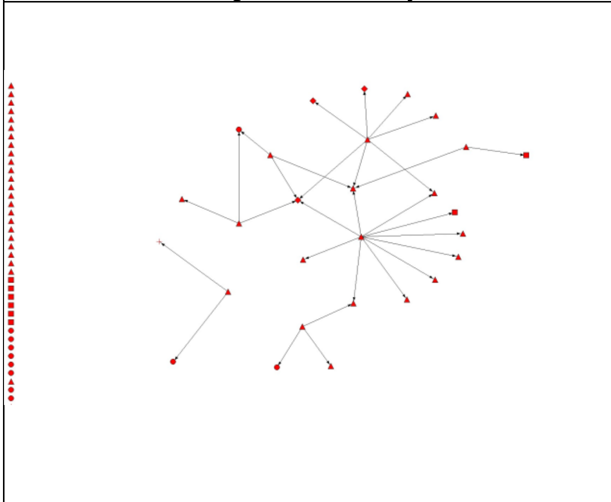
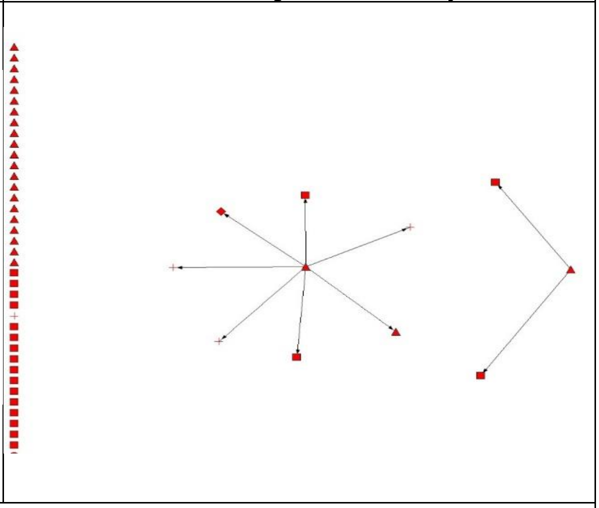
Fig. 4.4a Formal knowledge network in the Italian bioplastics industry	**Fig. 4.4b Formal knowledge network in the German bioplastics industry**
	
Note: *Triangles = firms; rectangles = research institutes/universities; plus = public institutions, circles = business support organizations; diamonds = NGOs/associations*	

Fig. 4.4 Formal knowledge network in the Italian bioplastics industry and the German bioplastics industry

Nonetheless, it is striking how joint patent development and patent licensing are way underdeveloped in Italy and do not exist at all in the German bioplastics niche - limiting formal knowledge share to staff exchange.

Tab. 4.2 Measures of the formal knowledge network

Network	Nr. of ties	Density	Inclusiveness	Clustering coefficient (overall graph)	Network centralisation (OutDegree)
Formal Knowledge (IT)	30	0.8%	46.66%	0.150	16.37%
Formal knowledge (D)	9	0.1%	12.6%	0	8.11%

4.3.3. Networking with powerful actors

As mentioned in Section 4.1, networking with powerful actors is the third important mechanism for the niche maturity. To investigate the presence of powerful actors in the informal and formal knowledge networks, surveyed firms were asked (in the last part of the third section of the survey) to indicate the actors they perceive as powerful in the development of the bioplastics industry. Power was defined in terms of technological development, financial resources mobilization, influence on public policies and instruments, as well as other service in support of bioplastics. The results emerged from this analysis are shown in figures 4.5 and 4.6 in the informal and formal knowledge networks respectively. The level of perceived power is illustrated in the network through the size of the nodes – higher the level of power, larger the size of the node.

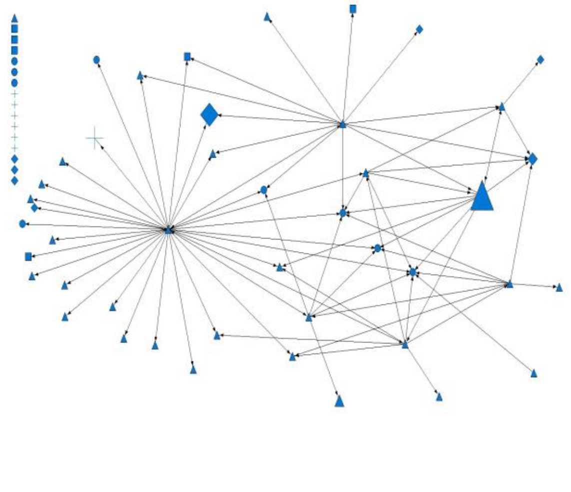
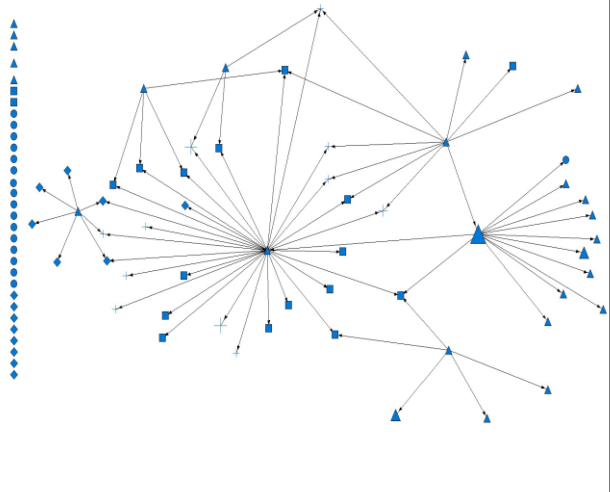
<table>
<tr><th>Fig. 4.5a Powerful actors in the informal knowledge network in the Italian bioplastics industry</th><th>Fig. 4.5b Powerful actors in the informal knowledge network in the German bioplastics industry</th></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Note: Triangles = firms; rectangles = research institutes/universities; plus = public institutions, circles = business support organizations; diamonds = NGOs/associations</td></tr>
</table>

Fig. 4.5 Powerful actors in the informal knowledge network in the Italian bioplastics industry and the German bioplastics industry

What emerges from this analysis is the presence of a handful of heterogeneous powerful actors in the Italian bioplastics industry. Specifically, the set of actors perceived as powerful is composed by two firms, two ministries, and two environmental NGOs. As we can notice in figure 4.5a, the perceived powerful actors do not occupy highly central positions in the Italian informal knowledge network (one of the environmental NGOs has only to links, one of the ministries and the second firm are at the extreme periphery of the network, and the second ministry is an isolated node). An important exception is provided by the most powerful actor in the Italian bioplastics industry, which is a firm well-connected to other actors in the informal knowledge network.

An overall similar picture arises when looking at the German informal knowledge network, in terms of number of powerful actors and their position in the knowledge networks. However, in the German case powerful actors belongs solely to two categories – i.e. three federal ministries and three firms. Out of this six actors only two occupy a central position (one firm and one federal ministry); all other actors perceived as powerful are at the fringe of the network.

The architectural structure of the formal knowledge networks, shows several similarities to the informal knowledge network, when considering powerful actors. The firm perceived as most powerful in the Italian bioplastics industry continues to have a central position in the formal knowledge network respectively to the other actors perceived as powerful, which also in this network are located at the fringe. In the German formal knowledge network, only one of the actors perceived as powerful is part of the main component of the network, although being peripheral as in the informal knowledge network. All other perceived powerful actors in the German formal knowledge network are isolated nodes.

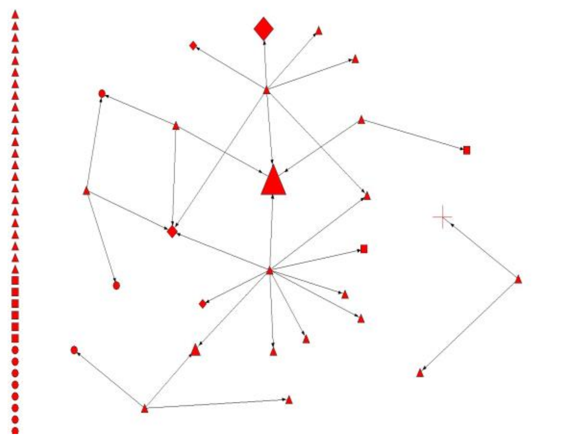
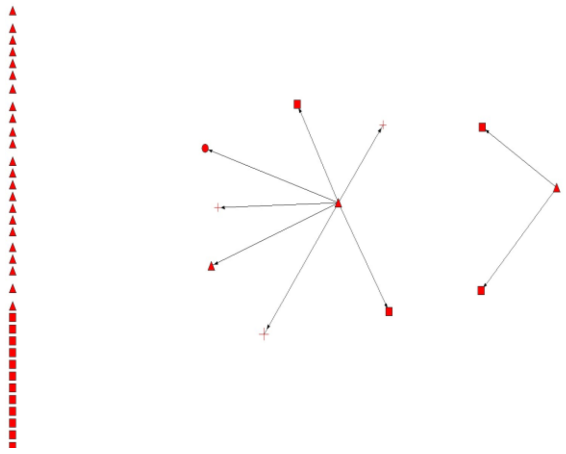
<table>
<tr><th>Fig. 4.6a Powerful actors in the formal knowledge network in the Italian bioplastics network</th><th>Fig. 4.6b Powerful actors in the formal knowledge network in the German bioplastics network</th></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Note: Triangles = firms; rectangles = research institutes/universities; plus = public institutions, circles = business support organizations; diamonds = NGOs/associations</td></tr>
</table>

Fig. 4.6 Powerful actors in the formal knowledge network in the Italian bioplastics industry and the German bioplastics industry

Overall, we can observe a positive occurrence emerging from this analysis, which is the presence in the network of various actors perceived as powerful. However, their position in the knowledge networks in both countries is not sufficiently central, hence their peripheral position in the network hinders a full exploitation of the resources for the development of both bioplastics industries.

4.4. Discussion and Conclusions

As anticipated in section 1.4, in this chapter we tested the influence of policy intervention in the structure of emerging niches. The comparative perspective on the bioplastic niches proposed in this chapter has brought some interesting insights both on the maturity level of the two respective niches in Germany and Italy, as well as on the emerging architectural properties of the underling social networks. These findings can well be linked to earlier results obtained by means of a comparative assessment of the main different policy measures undertaken in both countries: the German case being characterized by large public investments in R&D, whereas the Italian case mostly characterized by demand side policy which effectively created a market for bioplastic shoppers (Imbert et al., 2017).

First findings show that the bioplastics sector in both countries is progressing and currently trying to establish itself as a sustainably innovative regime. This output is based on the analysis of the three mechanisms of the Strategic Niche Management for both bioplastics niches in Germany and Italy.

As far as expectations are concerned, the future development of the bioplastic sector is characterized by generally high levels of expectations. However, in both countries key challenges undermining the niche development refer either to lack of policy support or to the changing and unstable institutional and regulatory framework. Technical knowledge and work force qualifications, on the contrary, are not conceived as a real threat to the niche development.

When considering the networking structure of the niche, some interesting similarities and differences emerged through the comparative exercise. The Italian bioplastics niche network includes few powerful actors that are peripheral; hence they don't dominate the network. However, the perceived powerful actors in the Italian bioplastics industry are more heterogeneous and composed of firms, public bodies, and environmental NGOs. On the contrary, the actors perceived as powerful in the German bioplastics niche network are less heterogeneous than the Italian one, composed only of public bodies and firms. Similarly to the Italian network, in Germany perceived powerful actors are few and peripheral.

Informal and formal knowledge networks in the Italian bioplastics industry are dense and highly inclusive, though composed mainly of firms. The actors perceived as powerful are few, however they are peripheral in the knowledge networks; hence they don't dominate the knowledge exchange flows. This intense knowledge sharing among italian firms is mainly due to the small size of firms composing the biplastics sector, together with a busy market boosted by the demand-side policy of the Italian government. Instead, the German informal and formal networks are characterized by the presence of a high variety of institutional actors actively participating in knowledge exchange. The anemic formal knowledge exchange, including few staff exchange and the complete lack of joint patent and patent licensing in the German case, is most likely associated with the important policy interventions in R&D coupled with large size of firms operating in the sector - almost 60% of all German firms involved in the bioplastics industry have more than 250 employees. A fact which is less dominant in the Italian context.

Far from being conclusive, this preliminary study brings to the surface a fertile environment for the niche development processes, which however still needs external support on its way to maturity. Perhaps, Italy and Germany could learn from each other's experiences: with the Italian niche needing to be more inclusive with respect to several institutional actors, research centres and NGOs, and the German niche needing to further stimulate formal knowledge sharing. Finally, in both countries extra efforts are needed to include perceived powerful actors within the emerging niche network, in order to attract more resources in terms of technological development, financial resources mobilization, influence in public policies and instruments, as well as other service in support of bioplastics.

Key findings and conclusions

In this thesis, the effort has been to deepen the analysis of particular aspects in the complex transitions studies: i) systematization of the spatial dimension of innovative niches, ii) the role of policy intervention in niche architecture and path breaking processes, iii) environmental issues as landscape pressure for transition, and iv) the extension of the concept of MLP in bio-based economy. The interesting findings we come out with in our several analyses, by means of various qualitative and quantitative methodologies, help enriching the sustainability transitions framework by refining the aspects mentioned above.

The key findings of this thesis are not introduced chronologically for each chapter, but they are presented for each level of the Multi-Level Perspective addressed.

At the niche level, we found out, through the simulations of an agent-based model in Chapter 3, that the geographical dimension of a niche - local, global, or mixed - is important in determining the timing of the niche emergency and the velocity of its journey to maturity, thus influencing in this way the transition process. In accordance with this finding, we propose the geographical dimension of the niche as the forth mechanism of the Strategic Niche Management since it does indeed play a role in shaping the niche journey to maturity, likewise knowledge, networking and expectations.

At the regime level, policy interventions are discussed as two conflicting positions, on the one hand, as compliant internal elements of the regime since they are developed by path-dependent institutions and are as well influenced by incumbent lobbies, and on the other hand, as struggling elements of the regime building favourable conditions for the development of niches. Indeed, we investigated the role of several policy interventions in boosting the niche maturity and in shaping the architecture of the niche, in Chapter 2 and in Chapter 4 respectively. Through an Argumentative Discourse Analysis in the Boston area, in Chapter 2 we showed how a well-developed niche of clean energy technologies - based on knowledge, networking, and expectations - struggles to establish itself as a new dominant regime in the absence of policy intervention, paticularly in terms of local commercialisation policy and enhancement of private investments. Moreover, the comparative Social Network Analysis of the bioplastics industry between Germany and Italy developed in Chapter 4 established a relation between the different policy intervention adopted by both governments and the characteristics of the bioplastics niches developed in both countries. The German case being characterized by large public investments in R&D, boosted research and innovation mainly within firms, since the German bioplastics industry is mostly composed of large firms. Determining in this way high levels of knowledge, but weak formal knowledge networks and networking with powerful actors. Whereas the Italian case mostly characterised by demand side policy, effectively created a market for bioplastic shoppers, taking advantage of an intense collaboration among firms in terms of informal and formal knowledge networking.

The landscape level does not represent a particular issue under investigation in this thesis for two main reasons: i) we have considered current environmental problems and the scarcity of raw materials as exogenous pressures that have already opened “windows of oppurtinity” for the emergency of innovative niches, and ii) since the landscape is not influenced by the outcome of innovation processes on a short and mid-term basis, we have focused on the dynamics of niche emergency and maturity as well as on the role of policy in niche empowerment.

Overall, as discussed in Chapter 1, the Multi-Level Perspective has been a valuable and suitable framework for analysing systemic transitions, such as the case of bio-based economy, that are more complex than the adoption and diffusion of a clean technology. This framework is appropriate for exploring transition dynamics as it allows analysing the diffusion of new production processes, new behavioural models, as well as changes in the institutional framework, which are at the base of the socio-technical transition studies.

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Annex 2 Interview Questions

- Please, describe your organization and the role it plays in the clean technology industry.
- Which correlated sectors/activities your organization has supported in order to encourage the clean energy sector?
- Which are the main drivers for your organization presence in the Boston area (MA)?
- Has your organization introduced innovative goods in the market, implemented innovative production processes or filed any green patent?
- Has your organization developed the innovation/patent on its own or in collaboration?
- What percentage of your organization R&D/innovation activity has been funded by public financial support/private organizations?
- Has your organization developed any kind of collaboration with other public agencies/private sector?
    - What kind of collaboration?
- In your opinion, what is the level of development of the clean energy sector in the Boston area as compared to other areas?
- In your opinion, why has the Boston area become one of the most successful hotspots in clean energy technologies?
- In your opinion, is qualified work-force an asset of the Boston area?
    - Which level of qualification in the clean energy sector do they have?
- Please rate the following statements on a scale from 1 (strongly disagree) to 5 (strongly agree)
    - The legislation supports innovative/patent-related activities
    - Special aid is available from the government for green innovative/patent applications
    - Starting up one's own business in the clean energy sector is encouraged in Massachusetts
- What do you think is the level of diffusion of clean energies used by companies and households respectively to the achievements of the research in this field?
    - For what reason?