Review article

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A Strategic Niche Management approach for shaping bio-based economy in Europe

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Abstract: The goal of this paper is to investigate the transition towards a bio-based economy as part of a broader sustainable transition in Europe. To analyse the challenges and opportunities associated with the bio-based economy, we applied the Strategic Niche Management approach to investigate the drivers that boost the emergence of the bio-based economy, the factors hindering it, as well as institutional changes which are at the base of the socio-technological transition. Although considered as just one piece of the sustainability puzzle, the bio-based economy behaves as a socio-technical system on its own, providing valuable hints on systemic transitions.

Keywords: socio-technical system, sustainability transitions, Strategic Niche Management, bio-based economy

1 Introduction

Back in 1789, Thomas Robert Malthus announced that a problem of natural resources availability would emerge. This theory, though radical and innovative at the time, did not consider the technological development, able to generate economic growth for decades within a context of demographic expansion (Wilson and Dragusanu 2008; Kharas 2010; Pezzini 2012; UN 2015). Notwithstanding, a 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 the environment. To "unlock" the current carbon lock-in and dismantle the linearity of the production-purchase-consumption-waste cycle, the challenge of human wellbeing and assurance of an increasing trend of economic growth must be addressed, while valorising natural and renewable resources in a sustainable way.

The focus of the analysis cannot only be on the production and supply sides of new technologies, but also on the fulfilment of social functions and environmental sustainability since society, economy, and environment are not separate systems but complementary elements of the same system. The coevolution of technological innovation with its diffusion mechanisms, its impact on and 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 that form a stable configuration (a dominant regime) that can resist, to some degree, the pressure of various sources that act outside and inside the system.

Therefore, the development of new radical innovations to address one element of the system is a necessary, though insufficient, condition to destabilise the regime. Rather, a dynamic transformation of the socio-technical system is needed to successfully challenge the dominant regime. A systemic transition toward a circular economy can be a solution to reduce the burden of growing population and people needs over global natural resources (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). Such transition would entail progressively moving towards a model in which: (1) natural and renewable resources (biomasses) replace fossil-based resources; (2) the production focuses on recovery of inputs along the whole value chain, including re-engineering efforts to produce goods from recyclable materials; (3) consumption aims at reducing, reusing, and sharing goods rather than owning them.

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Encouraging signs are pointing at this direction. For instance, there is an increase in research and development (R&D) effort to develop clean technologies that can reduce GHG emissions and save natural resources (Del Rìo Gonzales 2005; Frondel et al. 2007; Carley 2011). Additionally, there is a promising uptake of the principles of the bio-based economy, achieved with products made from renewable biological resources (Langeveld et al. 2010; Schmid et al. 2012; Vanholme et al. 2013; Pfau et al. 2014). There is also a rapid growth of sharing practices in consumption that are 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 paper is to investigate the transition toward a bio-based economy as part of this broader sustainable transition. The focus of the paper is to analyse challenges and opportunities associated with the rise and further development of such a bio-based economy in Europe. As we argue later on in this paper, the transition to a bio-based economy moves beyond the diffusion of single innovations. Rather, it unravels various and interacting technological, social, and institutional innovations that trigger a system transition. Behaving as a socio-technical system on its own, the investigation of the transition toward a bio-based economy can provide valuable hints for the analysis of the transition processes of the whole system's sustainability. Therefore, we apply the Strategic Niche Management (SNM) approach to explore the maturity of bio-based niches to destabilize the incumbent socio-technical system. This framework is appropriate for this research because it allows the investigation of the drivers that boost the rise of this system on the one hand, and – on the other hand – the factors that hinder it, as well as the institutional changes at the base of the socio-technological transition.

Accordingly, the methodology followed in this paper is based on a review of the literature published both on peer-reviewed field journals (with a focus on environmental issues) and of grey literature (including reports and policy strategies that have broader goals and do not focus particularly on environmental issues). The literature review is not exhaustive, but rather aims at providing an overview of the rise and development of the bio-based economy in Europe. Therefore, the method aims at providing an accurate search for and identification of relevant references in the literature to frame the European bio-based economy within an SNM approach. The relevant literature was screened with an emphasis on the three niche mechanisms of the SNM: i.e. learning processes, networking activities with powerful actors, and convergence of expectations of all actors involved in the transition process. The aforementioned approach allows the exploration of the degree of involvement of various stakeholders in the transition process towards the bio-based economy in Europe. By doing so, the paper seeks to present the view of the many stakeholders that participate in the value chain (including consumption and end-of-life options), from consumers and farmers associations to industries and European policymakers.

The remainder of the paper is structured as follows: Section 2 provides an in-depth overview of transition dynamics in an SNM approach, Section 3 discusses the bio-based economy as a systemic transition, paying particular attention to convergence of expectations on future developments, learning processes, and networking with powerful actors. Finally, Section 4 concludes the paper and discusses future challenges for the development of the bio-based economy in Europe.

2 Transition dynamics in a SNM approach

The technological evolution of the last three decades has triggered a flourishing debate on the factors of technological development, deployment, and diffusion, on the one hand, and on the unit of analysis, moving the focus from market failure to system failure, on the other hand. Innovation is a complex process, therefore the concept of innovation systems has 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 are more focussed on the functioning of systems and on the emergence of new systems (Geels 2004). Thus, they lack a broader perspective of transition from one system to another through substitution of technologies and transformation of sectoral structures (Geels 2004; Markard and Truffer 2008). A further criticism to the theory of innovation systems concerns the narrow definition of socio-economic factors within the selection environment (Geels 2004; Smith et al. 2010). In fact, this definition does not directly nor clearly refer to the demand side and to the

fulfilment of societal functions as drivers of technological innovation processes.

Accordingly, the concept of socio-technical systems (Geels 2002; 2004; 2005) has been developed to explain the causality and co-development of new technologies with new markets, new social structures, new actors and new institutional assets (Markard and Truffer 2008). The idea behind socio-technical systems is the existence of networks between and among actors that create autonomous but interrelated groups that interact according to structured rules. The incumbent socio-technical system behaves as a selection environment characterized by lock-in and path dependency mostly fed by incremental innovations (Geels 2005). In this sense, the transition to a bio-based economy as a radical and sustainable innovation process is a deviation from the incumbent socio-technical system. The question to be asked is thus how do sustainably innovative socio-technical systems destabilize stable and path-dependent systems?

According to the Strategic Niche Management (SNM) approach, the emergence of radical sustainable innovations is facilitated by the development of technological niches that are *"protected spaces that allow nurturing and experimentation with the co-evolution of technology, user practices, and regulatory structures"* (Schot and Geels 2008). Indeed, they are theorized as "protected spaces" since the performance of innovation at this stage is not able to address competition in incumbent markets (Smith and Raven, 2007). Niches are spaces where experiments on variations that do not fit the selection environment are developed. These on-going dynamics modulated with the SNM approach are generated by endogenous and bottom-up movements enacted by a multitude of actors, including users, producers, and societal groups, that launch the niche. When the rules do not fit everyone, moments of discordance may emerge and the radical innovations occurring in the niche start to put pressure on the incumbent rules demanding for change. It should be further noted that niches are not created by the government; however, government policies can boost or hinder the maturity process of a niche.

Three internal mechanisms are identified, within an SNM approach, in the evolutionary process to the niche maturity making the niche more stable and able to destabilize the incumbent path-dependent system. The first mechanism concerns the learning process that affects the production and accumulation of knowledge by the niche actors. The sharing of knowledge on new technologies is essential for private firms that may not have technological competencies and financial capacities sufficient to fully develop risky and radical innovations. This suggests that innovative performance of an economy is not generated by direct public and private R&D investments only; it is also affected by learning processes, networking activities and knowledge sharing among research institutions, universities, private firms and organizations with the support of public bodies (Lundvall 1992; Nelson 1993; David and Foray 1995; Debackere and Veugelers 2005). This is particularly relevant whenever the research needed for the development of a new technology (like clean technologies) is characterized by long-term timeframes, high costs and uncertainty. These factors discourage own R&D investments of private firms, thus making formal and informal learning as well as technology transfer highly important. The latter mechanism, defined as the transferability of technical know-how among organizations (Bozeman 2000), has two implications for our context: (a) public funding and regulations are needed to foster and increase public and private marketable research due to the long-term view and the risks associated with such research (Cantner et al. 2016); (b) technology transfer is grounded on a close collaboration between actors or, in other words, networking – the second internal mechanism for the niche development.

The building of a social network is a long process, but it is crucial for obtaining the essential resources required for the transition to innovative technologies (Smith et al. 2005; Lopolito et al. 2011). In the initial stage, the network is small and fragile; 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 for niche development.

Converging expectations are essential in bringing actors together and generating a common purpose, which the initial stage of the niche development lacks. 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 the needed infrastructural, institutional, and regulatory changes (Nissila et al. 2014).

Place-specific factors (e.g. innovative capacity, knowledge, local networking) are crucial for the emergence of the niche in the first stage (Hansen and Coenen 2015). However, the process of convergence of expectations, differently from the other two mechanisms, is mainly influenced by external pressures and circumstances

that are originated by problems at the incumbent socio-technical system 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 to a competitive space for sustainable innovation. This process is characterized by high competition in incumbent markets; the reason being that traditional technologies are economically affordable and supported by well-established artefacts and groups of interest within the incumbent socio-technical system. However, as sustainable innovations are important for the sustainable development of our society as they may correct a system failure by generating positive externalities concerning environmental issues (Knight 2010; Shellenberger et al. 2008; Acemoglu et al. 2009), they need regulation and non-monetary incentives.

Overall, socio-technical transition is not a simple and linear process (Smith et al. 2014). It is a rather complex political negotiation (Smith and Raven, 2012) among actors with conflicting positions and opinions. It also depends on framing and defining the process of institutionalizing innovation (Hajer 1995). The changes that entail transition must be systemic, focusing on the whole value chain and involving all actors as central to the development of path-breaking innovations. The latter must include: i) substitution of fossil fuel resources with biomass, ii) introduction of clean technologies in the production process, iii) reduction of consumption, and iv) valorisation of waste. These are four fundamental pillars of the transition to a bio-based economy as discussed further on.

3 The transition to a bio-based economy in Europe

For the deployment and diffusion of one radical innovation, a single niche deals with the inertia of the incumbent socio-technical system, while for the transition to a bio-based economy, which is composed of a wide range of economic sectors, several mutually supporting niches are simultaneously engaged in destabilising the incumbent socio-technical system. Indeed, within the sectors involved in the bio-based economy, several niches operate in developing different technologies to exploit renewable biological resources. Within a holistic investigation of a systemic transition, the whole system needs to be assessed rather than parts of the single sectors involved in bio-based economy. The complexity of the transition process of the system under investigation is linked precisely to the co-existence of several connected sectors (e.g. bio-fuels, bioenergy, bio-chemicals, biomaterials, waste management, sustainable feedstock production, etc.) and to the high variety of socio-economic actors that operate within these sectors (e.g. rural communities, waste collectors, consumers, industry, research institutes, environmental associations, etc.).

Nonetheless, attention is often placed on specific aspects in the definition of the bioeconomy given by national and international bodies, whilst the holistic approach is forgone. 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, by focusing on the key role of biotechnologies, does not provide adequate space for the role of society and agriculture in the bioeconomy system (Hausknost et al. 2017), which is defined as a technology-driven concept. Instead, BECOTEPS (BioEconomy Technology Platforms) defined 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 non-marketable elements such as biodiversity conservation, water quality and landscape (Jordan et al. 2007; Brunori 2013). Moreover, the European Commission, in its official strategy - *Innovating for Sustainable Growth: A Bioeconomy for Europe* - stated that the bioeconomy *"... 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, 2012); here the definition focuses on value-added products. The two latter definitions emphasise a resource-driven concept based on the transition from a fossil-based to a bio-based economic system (Hausknost et al. 2017).

The diverging visions which emerge from these definitions are generated by the different rationales, landscape factors, or by aspects which are internal to the European economic structure, used to explain the development of the bio-based economy. Pfau et al. (2014) identified three particular drivers, mentioned in the literature, to the development of the bio-based economy, reducing the dependence on fossil fuels: i) the decrease of available resources, ii) increasing costs of exploitation of fossil fuel due to increasing difficulty to reach oil reserves, and iii) the location of the reserves in geopolitically unstable regions.

Regardless of the multiple interests on stake for the preservation of the incumbent socio-technical system, the cost and uncertainties concerning traditional resources and production capacity is generating the need for alternative resources and innovative sustainable commodities.

A further driver discussed in the literature reviewed by Pfau et al. (2014) is related to population growth and to the need to secure the supply of energy, commodities and food. This driver regards the availability of resources to manufacture products and produce energy, leaving aside biodiversity and quality of the environment. In this case, the bio-based economy is expected to develop alternative (bio-based) resources with the help of innovative biotechnologies. Also within a climate change perspective, it is assumed that the development of a bio-based economy would preserve global climate. This, by creating added value through the reduction of negative environmental impacts from energy consumption, production processes, and waste disposal.

In the specific case of Europe, some further endogenous factors, which drive the bio-based economy in EU regions are listed in the report *Bioeconomy development in EU regions* (2017). Among others we shall mention: i) abundance of natural and biological resources that fuel the bio-based industry, ii) strong primary economic sector that can benefit from technological development for increasing productivity, iii) important chemical and other industrial sectors that seek a decoupling of own development from their dependence on fossil fuel resources, and iv) specialised higher education, as well as research and innovation activities within regions that increase knowledge on innovations for the bio-based economy as we will discuss further on in the paper. In this perspective, the regional landscape as well as the endogenous drivers both affect the way the bio-based economy is developed in Europe, supported by policy making and strategic decisions which can trigger economic development and tackle environmental challenges.

Indeed, several actors (e.g. national and regional policy-makers) have drafted strategies with commitments for the development of a bio-based economy in Europe (de Besi and McCormick 2015; Hausknost et al. 2017). Based on these strategies, in the next subsections we are going to examine the three mechanisms of SNM – i.e. convergence of expectations, learning processes, and networking with powerful actors – in order to discuss developments and challenges at the niche level of the several sectors that compose the bio-based economy and assess the transition process to a bio-based economic system.

3.1 Convergent expectations on future developments

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 and national strategies across EU strive to put in place regulatory and supportive policies and ensure coherence between policy measures and levels of government. The EU and national strategies have addressed this issue by creating interdepartmental panels, coordinating ministries and various departments. Public procurement has been identified as an important action to simulate bio-based markets and to nourish high expectations for the future of bio-based products. In more general terms, as mentioned in section 2, an important factor for building a common vision for the future of the bio-based economy is the pressure exerted by and the technological breakthroughs obtained 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 sharing (Wellisch et al. 2010; Schmid et al. 2012; Pfau et al. 2014) and networking with powerful actors.

3.1.1 Stocktaking of activities at European level

With the aim of increasing public awareness many European regions are actively trying to raise the visibility of Research and Innovation projects and activities concerning the bio-based economy. As an example, "*the Marshall's office of the Lodzkie region organises annually a bioeconomy congress in the city of Lodz. The purpose of the Congress is to create a friendly atmosphere around the innovative, effective and competitive approach to activities intended to support the development of bioeconomy...*" (Spatial Foresight et al. 2017: 72). Moreover, "*in 2013, the cluster 'Paper Province' was awarded a strategic project by the Swedish Innovation Agency, VINNOVA. The initiative is co-funded by a triple helix partnership consisting of the Paper Province members, Karlstad University, Region Värmland, the County Administrative Board, Local authorities and the Swedish Forest Agency. The vision of the initiative is for Paper Province to become a leading European competence node for a forestry-based bio economy in ten years' time. The aim is to create a large-scale demonstrator that from a service and systems perspective coordinates and demonstrate bio economy in practice. The objective is to set the stage for the 1000 new jobs and 25*

new businesses during one decade. The vision is to generate large number of projects, both national and international, including Horizon2020." (Spatial Foresight et al. 2017: 71).

The creation of new markets and the uptake of bio-based economy as a common vision for the future are grounded on the inclusion of society in bio-based activities. Undeniably, the awareness of consumers and end-users to environmental issues and to the public strategies to address environmental challenges are essential to allow a transition to a bio-based economy as it affects positively their behaviour toward bio-based products. Consumers are willing to accept sustainable and innovative products with sufficient guarantees on quality, safety, and security, considering the same range of price as traditional products (Almenar et al. 2010; Sijtsema et al. 2016). Additionally, 89% of the companies responding to a survey conducted by JRC strongly believe that European bio-based product sales will increase by 2020, and almost half of them expect an increase of more than 100%. Moreover, 72% of the responding companies forecast an increase in the share of bio-based output sold in the EU by 2020 with 41% of them expecting an increase of more than 100% (Ronzon et al. 2017).

3.2 Learning processes

The various bio-based economy strategies at all policy 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 plants and industrial processes conversion and pilot test areas to increase the level of technological readiness. This would help achieving a mature technology and industrial production that would lower the price of bio-based products[1], making them price competitive compared to traditional products. In order to do so, it is essential to understand how to develop a market-level technological readiness.

3.2.1 Stocktaking of activities at European level

Bearing in mind the importance of learning processes, many European regions are engaged in promoting specialised research and innovation centres for the bio-based economy within European research programmes and projects. Some important projects co-funded by national and regional governments and by European funding authorities, engaged in increasing knowledge by developing new value chains and/or using innovative resources, are the following:

1. The Danish Shellfish Centre in collaboration with the private company Vilsund Blue a/s completed a study in 2011 on the possibility of using compensation farmed mussels, smaller than the minimum size for fished mussels, for human consumption. The role of the municipalities in the project was to disseminate the results to relevant political and technical forums and to promote alternative use of compensation farmed mussels. (Spatial Foresight et al. 2017: p. 68-69)
2. The South Bohemian Research Center of Aquaculture and Biodiversity of Hydrocenoses (CENAKVA) developed a new infrastructure and research project co-financed by ERDF which aim is to develop high quality science, research and applications in the field of fishery, aquacultures and sustainable freshwater management system, all focused on fish farming and in-land waters, mostly in Europe (Spatial Foresight *et al.* 2017: p. 69)
3. The Microalgae biorefinery project, supported by the Climate-KIC initiative, has two objectives: (1) to verify and put into market algae-based product line thus creating the example for waste water treatment plants which can prove its operational advantages and (2) to integrate the new technology into an existing value chain which will allow to use biomass produced in waste water treatment plant to be turned into sources of new bio-based products. (Spatial Foresight et al. 2017: p. 70)

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

In order to implement current (pilot-scale) projects and to accomplish their industrial scale-up, interdisciplinary and specialized educational programmes are offered in order to increase qualified labour. Indeed, master courses and study modules have been prepared and launched across Europe. Among others, the first European master in Bioeconomy in the Circular economy (BioCirce), a collaboration of four Italian universities, two firms and a science park, was launched; the bachelor and master's degree at the University of Applied Science Upper Austria in food technology and nutrition is supported by the Upper Austria food cluster; a master program in Biotechnology at the International Faculty of Engineering (IFE) and the Faculty of Biotechnology and Food Science prepare interdisciplinary specialists with knowledge in chemistry, biology, and engineering (Spatial Foresight et al. 2017).

3.3 Networking with Powerful actors

The multi sectoral and cross-cutting characteristics of a bio-based economy demand for a systemic approach, where actors at all levels of governance develop several strategies in support of bio-based economy. The OECD[2], the EU[3], as well as national and regional agendas focusing on local capacities, strengths, and resources (de Besi and McCormick 2015; Doloreux and Parto 2005), are committed to promote a transition to a bio-based economy. Moreover, in the particular case of Europe, in 2010, the knowledge-based bio-economy paradigm has started to emphasise the role of public-private partnership in boosting the development of innovative bio-based products and processes for the industry (Albrecht et al. 2010). Indeed, these strategies identify the engagement of actors at all levels as essential, suggesting collaboration by means of research programmes, innovation networks, and the formation of industrial and research clusters.

Networking in the bio-based economy is particularly relevant in the case of biorefineries, for the application of the cascading principle, which entails an efficient and optimized use of biomass along the value chain. The fulfilment of this principle requires a strong and close collaboration of all stakeholders. Such collaboration should take place: (1) along the value chain in order to use the same biomass for multiple purposes – bio-chemicals, bio-materials, bio-fuels, etc.; (2) among countries for importing and exporting biomass; (3) between industry and governments, for building adequate infrastructures and logistics.

An additional challenge concerning the development of biorefineries and the application of the cascading principle is related to the lack of knowledge on how to integrate already existing value cycles for the production of high value added products. To tackle this issue, an engaged policy-driven strategy can help overcoming the lack of knowledge, generating at the same time positive returns on jobs and growth. Moreover, an active participation of the society in recycling and waste valorisation, considering end-of-life options, helps closing production loops in order to fulfil a complete life-cycle perspective for bio-based products.

3.3.1 Stocktaking of activities at European level

An issue which is important for the market uptake of a technology is its maturity, essential for technological commercialisation. This aspect requires strong collaboration between research institutions and industry covering all the bio-based sectors and building a strong network of technology transfer and knowledge sharing. As an example, the 3N "Network on Renewable Resources and Bioeconomy", a non-profit competence centre, is composed of 32 enterprises that initially could not afford research activities. At the moment, the competence centre provides access to research and innovation activities to its member enterprises. This is made possible thanks to the shared interests of the network, financed by its members and by other European projects. Similar services for research and innovation capabilities are offered by Kompetenzzentrum Holz GmbH (Wood K plus) located in Upper Austria, or by the Romanian Sustainable Energy Cluster. However, not only public bodies, research and innovation centres and business are important in boosting the development of bio-based economy, but also other stakeholders that can assure biomass supply and closing production loops along the value-chain.

The collaboration and networking among all these actors and stakeholders in the bio-based economy has generated some important regional (bio)clusters in Europe. Some examples, among others, are the following (Spatial Foresight et al. 2017: 26-27):

– Clusters organised around biological resources, e.g. Cork Cluster in Extremadura (ES), Paper Province Värmland (SE), Croatian Wood Cluster (HR), Cluster Inno'vin Bordeux-Aquitaine (FR).

2 See: "The Bioeconomy to 2030: Designing a Policy Agenda. Main Findings and Policy Conclusions".

3 See: "Innovating for sustainable growth: a bioeconomy for Europe".

- Agrofood clusters, e.g. Pôle Industries & Agro-Ressources (IAR) (FR), Food+i (North of Spain), Agri-Tech East (UK), Food Nordwest (DE), Food Cluster of Lower Austria (AT).
- Bioenergy clusters, e.g. Canterbury Bioenergy Cluster (UK), Cluster of Bioenergy and Environment of Western Macedonia (Greece), Dynamic Bioenergy Cluster Central Finland (FI).
- Industrial biotechnology/new materials/biorefinery clusters, e.g. CLIB2021 North Rhine-Westphalia (DE), Dutch Biorefinery Cluster (NL), GreenWin (Wallonie, BE).
- Sustainable chemistry clusters, e.g. Lombardy Green Chemistry Cluster (IT), Bioeconomy Central Germany (Sachsen-Anhalt, DE), Grangemouth Cluster (Scotland, UK).
- Bio-marine clusters, e.g. Pôle Mer Bretagne Atlantique (FR), Welsh Seafood Cluster (UK).

Successful collaborations based on the triple and quadruple helix model have been developed as well. Some of the concerned examples are (Spatial Foresight et al. 2017: pg. 72-73:

- Creating local innovation through a quadruple helix (CLiQ), funded with Interreg IVC 2007-2013, aims at strengthening the collaboration between local and regional policy authorities, universities, industry, and civil society in order to support innovation in medium-sized cities).
- Gate2Biotech (a platform for the biotechnological community in Czech Republic and Central Europe)
- Galicia Biotech platform (funded by ESF, regional government and regional development agency, IGAPE, and Bioga that is a non-profit business association)
- BioTecNorte (funded by the national and regional authorities, and ERDF funds)..

3.4 Criticisms on the sustainability of a bio-based economy

Although the transition to a bio-based economy is considered implicitly sustainable, some aspects of production processes and consumption behaviours related to biomasses are not. One critical aspect of this issue emerges in the 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). In a future perspective, when population is estimated to increase and, therefore, food and energy consumption will increase too (Morone, 2016), the sustainability concept of a bio-based economy grounded only on the substitution of fossil fuels with biomass might 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 to reach a truly sustainable 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 as a final step it can be converted into energy source. In this perspective, to reach high levels of resource efficiency, the development of integrated biorefineries using the cascading principle is crucial (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 strong collaboration among, on one hand, sectors bringing agriculture and industry together and, on the other hand, among actors to provide strategic and financial support in terms of infrastructure that would allow a complete exploitation of biomass.

Finally, the fossil carbon consumed today cannot be fully substituted nor with agriculture and forest alone, neither with the additional use of innovative forms of biomass such as micro and macro algae (Staffas et al. 2013). The simple replacement of fossil fuels with biomass, without other systemic changes, is not a viable way out of the fossil-based economy. Energy consumption that amounts to 500EJ, for example, cannot be satisfied by the energy produced with biomass grown on land that is estimated to be 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). For this, there is the need to stress the sustainability and environmental benefits that are closely connected to production processes and consumption patterns. In this context, one solution to overcome such limits of a full development of a sustainable bio-based economy can be the confinement of the human activity into 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).

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

4 Discussion and conclusion

In this paper, the bio-based economy, a system fuelled by radical socio-technical innovations, is discussed in an SNM perspective, in order to provide some hints on the challenges and opportunities associated with the establishment of such an economic system, and in particular with the transition from the use of fossil-based resources to renewable and natural ones.

The advantage of using SNM is its ability to explain system innovation, thus the transformation of one system into another one, more sustainable, through the investigation of innovative niches emergency. Although the bio-based economy is composed of a variety of sectors, each of which might develop several technologies for exploiting renewable biological resources, there is the need to consider it as one socio-technical system with its own innovation niches. This, for two reasons: on the one hand, the transition from fossil-based resources to bio-based ones requires a transformative change of an incumbent socio-technical system, influencing both the development of novel technologies for a sustainable exploitation of resources, and the awareness of society to environmental challenges and sustainable options. On the other hand, the bio-based economy benefits from cross-sectoral innovations, based also on the cascading approach, which is one of the pillars of the transition to a bio-based economy. For this reason, looking at bio-based sectors singularly does not add much to the understanding of the bio-based economy transition.

Having in mind the three mechanisms of SNM, in this paper we showed how the bio-based economy in Europe is affected by important learning processes and technological development, dense networking in research and innovation clusters, and high levels of expectations regarding the supply and demand of bio-based products.

While the EU-28 bio-based economy generated an estimated turnover of around EUR 2.2 trillion and employed 18.6 million people, 8.5% of the total EU workforce, in 2014 (Ronzon et al. 2017), its overall maturity is heterogeneous, depending mainly on two elements: i) the sectors considered, and ii) the Member State's local resources and economic orientation. According to the study on Bioeconomy developments in EU regions (Spatial Foresight et al. 2017), most regions and countries have an average bio-based economy maturity level. Another interesting finding of this study is that regions and countries positioned in the lower bio-based economy maturity levels contribute more on the intermediate steps of the value chains, i.e. biomass supply and waste and biomass conversion and processing.

The divergence in the 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 still 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). Some of the bottlenecks in the development of the European bio-based economy are related, but not limited to, the following shortcomings: there is no common definition and understanding of the bio-based economy and of the sectors involved, nor are there specific bio-based economy strategies in all European regions and Member States as well as any clear distribution of roles and responsibilities. Moreover, there is no allocation of funds for the development of a bio-based economy nor any support to SMEs in innovation activities through knowledge transfer or integration of value chains (which could support downstream and upstream production processes). Finally, there is need for more qualified labour and highly specialised education on bio-based economy, need for standards, regulations and incentives in order to reduce the risk of dealing with innovations on bio-based production, and more general need to increase all stakeholders' awareness on the benefits expected by the full deployment of a bio-based and circular economy.

To exploit the potential of the European economic system, the concept of the bio-based economy must be integrated with the circular approach. The development of integrated biorefineries using the cascading principle, strong collaboration and networking among all sectors with a particular attention on agriculture, and the increase of efficiency in order to reduce overconsumption of raw materials and waste would pave the way for the sustainability transition to bio-based economy.

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