Biotechnology vs. the Bioeconomy

WORKING PAPER

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Abstract

The bioeconomy is steadily becoming more important to regional, national and European public policy. As it encompasses the transformation of agricultural, marine and organic resources into food, feed, fuels, energy and materials, the bioeconomy should become a major new industry replacing oil-based products. However, policymakers take two main approaches to developing a bioeconomy. The first, technology-based approach depicts the bioeconomy as a biotechnology subsector. The second, resources-based approach (i) considers biomass transformation as its starting point, (ii) raises the issue of bioeconomy sustainability, and (iii) considers biotechnology as just one transformation technology, among others. But the growing literature on the definition of the bioeconomy has not yet covered the articulation between biotechnology and bioeconomy. This paper fills this critical gap and provides policy recommendations depending on whether the goal is to develop biotechnology or to contribute to green growth or sustainability.

Keywords: biotechnology; bioeconomy; sociotechnical regime; policy mix; sustainability

Highlights

- Two main conceptions of the bioeconomy: biotechnology or biomass focused
- The biotechnology industry and the bioeconomy have two different sociotechnical regimes
- The biotechnology industry is a technology provider for the bioeconomy
- Suitable policy mixes are required, depending on expectations for the bioeconomy

Since 2012, the term 'bioeconomy' has appeared increasingly often in the literature (Ronzon et al., 2017; Bugge et al., 2016; McCormick and Kautto, 2013; Schmidt et al., 2012), and in public policy, with the publication of technological roadmaps for countries, regions, industries and value-chains (EU, 2012, 2018; OECD a, b, c, 2017; Spatial Foresight et al., 2017; Staffas et al., 2013). The bioeconomy aims to tackle five main expectations: ensuring food security, managing natural resource sustainably, reducing the use of fossil resources and replacing fossil-based materials, mitigating and adapting to climate change, and contributing to job creation and rural areas development (EC, 2012). Hence, the bioeconomy is expected to produce chemicals, materials and energy, as well as food. Despite these substantial expectations, the meaning of "bioeconomy” is not clear. Most previous bioeconomy research is based on literature and policy surveys (Meyer, 2017; Hausknost et al., 2017; Bugge et al., 2016; de Besi and McCormick, 2015), without considering actual innovation and industry in the bioeconomy (Bauer et al., 2017). Describing the 'bioeconomy' clearly in terms of innovative economic activities is vital if we are to define a coherent policy to promote the development of the bioeconomy. This paper aims to fill this gap.

Two main industrial approaches coexist (Levidow et al., 2018; Levidow and Birch, 2012; Schmidt et al., 2012). The first defines the bioeconomy through the lens of biotechnology. The OECD defines the bioeconomy as "*a world where biotechnology contributes to a significant share of economic output*"[1] (OECD, 2009, p. 15). It considers that the emerging bioeconomy is likely to involve (i) the use of advanced knowledge of genes and complex cell processes and (ii) the

1

development of new processes and products. Consequently, in this approach, the bioeconomy is a subsector of the biotechnology industry. But the bioeconomy is also defined as the substitution of biomass for oil-based products. The European Commission (EC) defines the bioeconomy as "*encompassing the production of renewable biological resources and the conservation of these resources and waste streams into value added products, such as food, feed, biobased products and bioenergy*" (European Commission, COM 2012, p. 9). It considers that this economy may be circular and sustainable (EC, 2018). In this definition, focusing on biomass processing for food and non-food applications, the use of new scientific and technological knowledge is secondary. The bioeconomy is merely characterized as processing renewable resources from agriculture, forestry, fisheries, food, pulp and paper production, and parts of the chemistry, biotechnology and energy sectors (Langeveld et al., 2010). In these processes, the common denominator linking industries is not biotechnology but the transformation of biomass, mainly in biorefineries, which transform the biomass using different technologies drawn together in complex knowledge bases (van Lancker et al., 2016).

Three issues are at stake here. First, are the “biotechnology bioeconomy” and “biomass bioeconomy” approaches significantly different, apart from in their focus on technology or on biomass? Second, how are these two bioeconomies related? Is the bioeconomy a subsector of the biotechnology industry? Or is the biotechnology industry a technology supplier for the bioeconomy? Third, do these bioeconomies require different policies?

To answer these questions, I follow Acquier et al. (2017) in looking for actual practices to define emerging and contested fields. Moreover, the biotechnology industry has been well known since the seminal work of Arora and Gambardella (1990), but the bioeconomy lacks a clear definition. This paper depicts the biotech industry and the bioeconomy as sociotechnical regimes (Geels, 2004; Holtz et al., 2008; Smith and Raven, 2012; Svensson and Nikoleris, 2018; Sorrell, 2018). The paper is organized as follows. The literature review section (1.) highlights the unclear relations between biotechnology and the bioeconomy, and demonstrates why we take a sociotechnical regime approach to answer our questions. The second section (2.) highlights the methodology used in this study. The

Biotechnology is the deliberate application of simple biological agents or components of cells in production processes third section (3.) presents the results of the bioeconomy and biotechnology from a sociotechnical regime perspective. The fourth section (4.) discusses the results of the study in terms of future public policy. Finally, the conclusion draws perspectives for future research.

1. Literature review

1.1. The unclear relations between biotechnology and bioeconomy

Both the institutional literature and more critical analysis assume that biotechnology and bioeconomy are interrelated. However, the links between them are not clearly established, or are defined from a normative perspective, in terms of what they should be. In the early bioeconomy literature, policymakers and scientists described biotechnology as the heart of a "bio-based economy" (OECD, 2009) since it has been strongly linked with the development of European Union life sciences research and with expectations of a new growth cycle using science-based industries (Patermann and Aguilar, 2018). Hence, EU Framework Programme 7 describes the application of biotechnology with agriculture, fishery and forestry as the "Knowledge Based Bioeconomy" (KBBE; Aguilar et al., 2009, 2013). Here, the KBBE actually meant a bioeconomy driven by biotechnology. Several policy papers defend the key role of biotechnology in the development of the bioeconomy (Lokko et al., 2018; Malyska and Jacobi, 2018; Philp, 2018; OECD, 2017, a, b, c; Burns et al., 2016).

Alongside these claims, the European Union defines the bioeconomy not by the use of a specific technology, but by the goal of transforming biomass into feed/food, energy and materials, especially in biorefineries, to replace oil-based resources (EU, 2012, 2018). Several widely circulated EU policy papers and reports point out that other technologies (thermochemistry, natural oil-based processes, mechanical processes) may also be applied to biomass (whether from forests, agriculture or waste) (EU, 2012; Spatial Foresight et al., 2017; Vivien et al., 2019).

Several authors have highlighted the existence of competing narratives in the bioeconomy (Bauer, 2018; Bugge et al., 2016; Vivien et al., 2019). The most critical studies depict the strong emphasis on industrial biotechnology in the KBBE in as a “master narrative”, encompassing competing paradigms and making the biotechnology paradigm dominate other, non-technological conceptions of the bioeconomy (Birch et al., 2010; Levidow et al., 2012; Schmidt et al., 2012). They consider that the KBBE and EU definitions of the bioeconomy in 2012 are the same, without considering the range of technologies used. Other studies defend either the use of renewable resources (Scarlat et al., 2015) or sustainability issues as a starting point for the bioeconomy (Pfau et al., 2014; Ramcilovic-Suomiven and Pülz, 2018), or else the central role of the biorefinery rather than biotechnology (Bauer et al., 2018; Bauer, 2018; Morone et al., 2019).

This shows that the bioeconomy literature considers either that biotechnology is the heart of the bioeconomy (following the OECD) or that the features of biotechnology (Levidow et al., 2018) contradict what a bioeconomy should be. No previous publications consider the bioeconomy as a sociotechnical regime with its own features.

1.2. Depicting sociotechnical regimes

Originally, regime referred to shared cognitive routines among engineers developing technology (Nelson and Winter, 1982; Malerba and Orsenigo, 1993, 1997). Technological regimes are embedded in sectoral innovation systems (Malerba, 2002, 2005). In this framework, regimes mostly refer to accessibility, opportunity and cumulativeness in sectoral innovation systems. Drawing on this literature, Rip and Kemp (1998) define "technological regime" as *"the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of defining problems – all of them embedded in institutions and infrastructures"* (Rip and Kemp, 1998, p. 340).

Geels (2002; 2004) broadens the notion of technological regimes to include the notion of sociotechnical regimes, considering that additional communities are involved in the innovation and technological change process: users, public policymakers, social groups, suppliers, scientists, etc. They form "*the deep structure that accounts for the stability of an existing socio-technical system. It refers to the semi-coherent set of rules that orient and coordinate the activities of the social groups that reproduce the various elements of socio-technical systems*" (Geels, 2011, p. 5). Thus, the so-called "sociotechnical regime" encompasses the following seven dimensions: cultural and symbolic meaning; guiding principles; knowledge bases; industrial structure and networks; technology, infrastructure and artefacts; public policies; and markets and user practices (Geels, 2002; Markard et al., 2012). Hence, the sociotechnical regime concept has three strengths (Markard and Truffer, 2008): (i) a sociotechnical regime is a multidimensional concept covering technologies, institutions, practices, and forms of knowledge; (ii) it highlights the coherence of regimes through studying their interrelated components; (iii) the regime structure influences innovation strategies and development.

However, the regime concept has been questioned. First, the strong focus on rules in regimes, leaves aside the material dimensions of socio-technical systems, downplaying the impact of material aspects of physical artefacts such as infrastructures, political and economic power, and the effect of economic incentives (Markard and Truffer, 2008; Sorell, 2018). Hence, to express the structure of the system, sociotechnical regimes need to be analysed as configurations of material relations (Svensson and Nikoleris, 2018). Second, sociotechnical regimes are often depicted as homogeneous and coherent. Fuenfschilling and Truffer (2014) contest this view, stating that the stability of regime configurations is an empirical question, because regimes can be more or less institutionalized and more or less stable due to actors competing for legitimacy. Regimes are thus semi-coherent configurations. Third, an early critique of the sociotechnical regime stated the problem of the right level of aggregation and regime delineation (Geels, 2011). The methodological answer is to consider regime identification as an empirical question, which is the case here. It is expected to draw the picture of the bioeconomy regime in order to sketch policy options. Moreover, regime should be used to highlight the links between its various elements, the multidimensionality of the regime and its effect on innovation processes (Markard and Truffer, 2008).

2. Methodology

To describe and contrast the two regimes (biotechnology industry and the bioeconomy), we gathered empirical data from various sources: reports, scientific publications, stakeholder interviews, national and European events, and conferences observations.

The reports were mainly published by public institutions (European Commission, OECD), semi-public organizations (the Biobased Industry Consortium, the NNFC), publicly funded research projects (StarProBio, Biorefinery Euroview, Biopol) or national public bodies (Finnish VTT, French INRA, etc.). The scientific publications came from journals in both social sciences (including Biobased and Applied Economics, Sustainability, Resources), and chemistry and biotechnology (including Biofuel, Bioproducts and Biorefineries; Green Chemistry; New Biotechnology). We identified the articles using a scopus search, using "bioeconomy", "biotechnology", "biorefinery", "bio-based economy" as keywords, and through a system of scientific watch.

To complete the empirical literature review, we conducted 27 semi-directive interviews lasting 45 to 120 minutes, between January 2017 and November 2018. The respondents included chemists and biotechnologists (researchers and engineers; head of research units), consultants, industry representatives (national and European), industry members (top management), social science researchers, and public authorities (local, national and European authorities). These interviews aimed to identify the main differences and similarities between the bioeconomy and biotechnology. During the interviews (under confidentiality agreements), which we recorded and transcribed, we asked follow-up questions to clarify imprecise answers.

	Number of interviewees	Date
Researchers and engineers	4	March-September 2017 / June 2018
Consultants	3	January-December 2017 / October 2018
Industry representatives	3	March-September 2017 / June-November 2018
Industry members	9	March-December 2017 / January-June-November 2018
Social Science Researchers	4	January-June 2017 / March-June-November 2018
Public authorities	4	January-June-December 2017 / January-June-November 2018

Table 1: Details of the repartition of the interviews

We completed our literature review and interviews by observing five national conferences and seven European bioeconomy conferences (all of which were organized by either public bodies or industry associations). Finally, we presented the results of the study at three closed-door seminars with bioeconomy stakeholders to check the accuracy of our results.

To analyse our findings, we used the features of the sociotechnical regime (cultural and symbolic meaning; guiding principles; technology, infrastructures and artefacts; guiding principles; industrial structure; user relations and markets; policy and regulations) as categories (see section 2.2. for a detailed presentation of sociotechnical regimes).

3. Results: technology-oriented industry vs. biomass-oriented industry

3.1. The biotechnology sociotechnical regime: a technology-oriented industry

3.1.1. Cultural and symbolic meaning of biotechnology

OECD countries have made great efforts to support and the spread of biotechnology throughout the economy (OECD, 2009, 2017a). Biotechnology development is rooted in the extension of 'traditional biotechnologies' towards genetic manipulation and synthetic biology (Bud, 1991). Its promoters expect biotechnology to be crucial for the development of a bioeconomy by making scientific breakthroughs that produce a new wave of Schumpeterian innovations (Levidow et al., 2012). The promise of an industrial revolution lies at the heart of biotechnology. In this view, biotechnologies are 'general purpose technologies,' usable in health, agriculture, and, as far as this paper is concerned, in manufacturing industry (mainly chemicals and materials) (McKelvey, 2007; Aguilar et al., 2013). This hegemonic strategy of the biotechnology industry has been strongly criticized for commodifying seeds that impose life-science multinational monopolies over peasants; reducing food quality, leading to nutrition issues; and developing new organisms, potentially designed for environmental engineering, which may disturb ecosystems (Heller, 2002; Bonneuil et al., 2008; Brandt, 2014; Sarrazin and Lecomte, 2016).

3.1.2. Guiding principles of biotechnology

The biotechnology industry is technology driven, rooted in the development of biotechnology processes and in an institutional architecture dedicated to the search for innovation through biotechnology, knowledge commoditization and biotechnology diffusion (Bud, 1991; Coriat et al., 2003; see 3.1.4.). As a general-purpose technology, biotechnology targets many areas (OECD, 2009).

As an illustration, biotechnologies are classified by colours illustrating the targeted sector: red for health biotech, blue for marine biotech, gold for nanotech, and, most importantly for our case, green for agriculture and white for industry.

3.1.3. The knowledge base of biotechnology

The term "biotechnology" covers two streams of research and applications. First, it refers to the manipulation of genomes to synthesise valuable products, following the discovery of DNA structure in 1953 and the identification of protein synthesis and regulation in 1963, which paved the way for synthetic biology. Second, it refers to the inherent reaction capacity of microorganisms or biological agents for product development (such as yeast in the wine and brewing industries) (Bud, 1991).

3.1.4. Industrial structure and networks in biotechnology

From the biotech perspective, start-ups are core organizations for new knowledge production (Audretsch, 2001). Such firms can be academic spinoffs or purely private entities (Wright et al., 2008). Start-ups are associated with the heroic figure of the Schumpeterian entrepreneur making a scientific breakthrough providing techno-scientific promises, and thus gaining both private venture capital (VC) and public funding. Increased access to Intellectual Property Rights (IPR) since the Bayh Dole Act and new technology markets support the start-up model (Arora et al., 2001; Mowery and Sampat, 2005). Biotechnologies use both public and private funding. The introduction of new financial regulations enable the creation of small and medium-sized firms specializing in basic research and in producing and selling scientific knowledge. In particular, in 1984, the so-called 'Alternative 2' market on NASDAQ opened the way for a "*finance-driven model*" of innovation (Coriat and Orsi, 2002). This model led firms to focus on increasing their capitalization instead of developing products to turn IP into assets they can sell on technology markets (Andersson et al., 2010). Because shares are bought and sold by investors, their value has to increase continually (Hopkins et al., 2013), especially via techno-economic promises.

3.1.5. Technology, infrastructures and artefacts of biotechnology

The field of biotechnology developed through several well-documented artefacts: science-based start-ups, markets for technology, and the financialization of start-up strategies. Publicly funded research should give rise to start-ups, which will then be sold on markets for technology (Arora et al., 2001). The development of white biotechnologies raises the issue of their industrialization and incorporation in biorefineries. To tackle this issue, pilot and demonstration plants (Hellsmark et al., 2016) like *TWB* (Toulouse, France) or *Bioprocess Facilities* (Netherlands) prepare the industrialisation of biotechnology processes.

3.1.6. Public policies in biotechnology

R&D policymakers have paid close attention to biotechnology as part of the bioeconomy. They have defined entrepreneurship policies combining a strong focus on start-ups (OECDa, 2017); an extension of the patent system to allow broader inventions and patentees; easing of commoditized knowledge transactions (e.g. the WIPO green technology platform); direct R&D subsidies (from NIH in the USA for example); calls for research (since 1977 in Europe) and industrial projects; and the description of biotechnology as a Key Enabling Technology in the Horizon 2020 programme (Aguilar et al., 2013). Funded programmes have encompassed not only science and technology development, but also initiatives to forecast future biotechnology developments. The goal of such programmes is to develop actor-networks linking research and industry. In these networks, actors have to define "visions for the future", especially in the "European Technology Platform". The Lisbon Strategy (2000), followed by the Knowledge Based Bio-Economy (2005; KBBE), organized these networks (Schmidt et al., 2012). Consequently, the KBBE is strongly linked with biotechnology. Birch (2017) labels as "life science" this alliance between a part of the biotechnology industry (white biotechnology, *i.e.* industrial biotechnology) and agro-industry incumbents.

3.1.7. Biotechnology markets and user practices

Most biotechnology markets are in health. However, we focus here on industrial biotechnology (i.e., white biotechnology). This includes chemistry (commodity chemicals, speciality chemicals, and consumer chemicals), polymers and fibres, and active pharmaceutical ingredients. According to Festel et al. (2012), biotechnology sales should increase from €91.9 billion in 2010 to €515.1 billion in 2020. While in 2010, each sector had a roughly equivalent market share (between 15% and 22%), the shares for polymers and fibres, consumer chemicals, and speciality chemicals are expected to be the largest in the future. This can be explained by the fact that biotechnology processes are far more expensive than oil-based processes, and speciality products can sustain higher production costs.

3.2. The bioeconomy sociotechnical regime

3.2.1. Cultural and symbolic meaning of the bioeconomy

The bioeconomy means the replacement of fossil oil-based products with biomass, as in the expression "biobased economy" (Langeveld et al., 2010). The European Union's view of the bioeconomy is becoming dominant (Morone et al., 2019; Bauer, 2018). The EU Communication setting the European bioeconomy agenda highlights the following "societal challenges" for the bioeconomy: ensuring food security, managing natural resources sustainably, reducing dependence on non-renewable resources, mitigating and adapting to climate change, creating jobs, and maintaining European competitiveness (EC, 2012). Hence, its promoters see the bioeconomy as a source of green growth (Viaggi, 2018). These challenges may be achieved through a core artefact: the biorefinery (EC, 2012). This concept has been developed by firms in agro-industry, chemistry, the wood sector and biotechnology to represent the transition toward the use of renewable resources to imitate the chemical paradigm of fossil oil: cracking the input, purifying the chemicals, and reforming them into intermediate products (Kamm et al., 2005; Näyha and Personen, 2014). Nevertheless, the sustainability of this bioeconomy remains debatable. The use of biomass is not sustainable *per se* (Giampietro and Mayumi, 2015). Hence, the biorefinery may raise sustainability concerns, especially through its circularity or cascade approach (EU, 2018; Bell et al., 2018). But the bioeconomy may also be defined as a transition process toward strong sustainability, focusing on agroecology, for example (Vivien et al., 2019). Hence, the bioeconomy may become another sector including agriculture, chemical industry, biotechnology and forestry, or a driver of transition towards a sustainable society.

3.2.2. Guiding principles of the bioeconomy

The bioeconomy follows different guiding principles for biomass processing, mainly through the biorefinery. This artefact emerged at the beginning of the millennium, at the meeting point between two dynamics. First, there was the issue of using abundant available biomass. Since the end of the 1980s, agro-firms were searching for new outputs for their excess production. For example, firms like Cargill explored the production of bio-based plastics. Because they already knew how to produce non-food applications, agro-firms launched research programmes. Second, growing criticism of the chemical industry led to the development of 'green chemistry' based on twelve principles (Anastas and Warner, 1998). Since the beginning of the millennium, the seventh principle, covering the use of renewable resources, has become preeminent, under the influence of agro-industries (Garnier et al., 2012). So, public and private players inventoried the top 12 – reduced to 10 – 'molecules of interest' that carry strong techno-economic promise for food and non-food applications (Werpy and Petersen, 2004; Bozell and Petersen, 2010; Becker et al., 2015). This strategy opened up two competing ways of conceiving product development. The first was a 'drop-in' strategy: replacing an oil-based molecule with exactly the same molecule, but bio-based ("drop-in substitution" in what follows). Second, new product development strategies drawing on biomass functions (biodegradation, lightness, etc.; "novel function substitution" in what follows) (de Jong et al., 2012).

Therefore, whereas biotechnology is a technology-driven field, the bioeconomy is 'mission-driven' (Aguilar et al., 2013). The 'biorefinery bioeconomy' pursues two related objectives: (i) to unify the transformation of renewable resources for food use (human and animals) and non-food uses (chemistry, materials and energy) in biorefineries; and (ii) to make biorefineries ecologically and economically sustainable.

3.2.3. The knowledge bases of the bioeconomy

The bioeconomy knowledge base is heterogeneous, but in the process of unification, especially via pluridisciplinary research programs (Lewandowski, 2018). Biotechnology is one of four knowledge bases (de Jong et al., 2012; Laibach et al., 2019), alongside thermochemistry, oil-based chemistry and mechanical/one-pot processes. Available technological choices are constrained in several ways. First, different technologies can produce the same drop-in product, leading to a competition between technological trajectories that does not exist in biotechnology (Cherubini et al., 2009). Second, the biomass is diverse. It can originate from dedicated crops (cereals, palm oil, beets, miscanthus, etc.), agricultural co-products (straw, bagasse), food industry waste (poultry, cooking oil, milk) or from the sea (algae or microalgae). Third, biomass and technological choices are interrelated, because technological efficiency depends on biomass choices (Kamm et al., 2005).

3.2.4. Industrial structure and networks in the bioeconomy

The bioeconomy model differs first in terms of actor networks. Besides biotechnology start-ups, the pulp and paper industry, agro-industry and the chemical industry are involved in the bioeconomy. Although biotechnology start-ups carry a promise of technological breakthrough, such firms do not possess sufficient technological and organizational knowhow to market their products or to scale their production (Mustar et al., 2008; Patrucco, 2014). Therefore, knowledge production and diffusion throughout the bioeconomy are stimulated by calls for projects aiming to structure interactions between actors who draw on a variety of knowledge bases.

These alliances can be research projects, joint ventures, or take the form of equity funding (Audretsch et al., 2005; Belussi, 2016). They may also occur in pilot and demonstration plants (Hellsmark et al., 2016). For example, Eurobioref and Biocore were two major projects that defined biorefinery business models (Dubois, 2011) and demonstrated the need to develop pilot plants and technological platforms involving different players in production. Moreover, the concluding conference for these projects (Brussels, 2014) revealed the need for funding these shared structures. These two projects paved the way for the development of several open innovation demonstration platforms (e.g. Biovale in the UK or BioBase Europe Pilot Plant in the Netherlands and Belgium) as keys to coordinate knowledge production and diffusion across value-chains with public funding (Fevolden et al., 2017).

3.2.5. Technology, infrastructures and artefacts of the bioeconomy

The bioeconomy has also developed different artefacts. First, as described earlier, the biorefinery acts as a unifying artefact, especially through the use of a second artefact: backcasting. Backcasting is a planning methodology, inspired by organization management and energy production planning (Robinson, 1982; Vergragt and Quist, 2011). Backcasting can be considered an artefact because of its methodology. Starting from possible futures, backcasting defines pathways to reach them, identifying technological lock-ins to solve through innovations nurtured in niches. Hence, they produce orientation and then contribute to a vision of the future and to navigation governance (Geels and Raven, 2006; Langeveld et al., 2010; van Lente, 2012). The first use of this method for a biorefinery dates back to 1999 with the 'Plant/Crop Based Renewable Resource 2020' programme. The report 'Top Value-Added Chemicals from Biomass' (Werpy and Petersen, 2004) pursued this idea, identifying promising drop-in molecules (see also Bozell and Petersen, 2010). The European Joint Research Centre imported this methodology in 2005 for its report 'Techno-economic Feasibility of Large-scale Production of Bio-based Polymers in Europe' and for projects such as BREW (2006) and Biorefinery Euroview/Biopol (2008). These last two projects identified players in several sectors (chemistry, pulp and paper, sugar/starch, biofuel, bioenergy, petro-chemistry, etc.) that might become involved in the bioeconomy. Each project results in several biorefinery typologies with the same objective, that of imitating petro-chemistry.

Following this framing, public players (regions, states, states coalitions like Nordic countries, etc.) defined strategic roadmaps toward the bioeconomy (OECDc, 2017). These roadmaps act as inventories of major activities and technologies that can become part of the bioeconomy (like the wood sector in Finland), and define a vision for the future of the region covered by the roadmap, and tools to sustain the emergence of the bioeconomy (Staffas et al., 2013). Third, many academic publications define possible technological futures. These reviews (for example see Cherubini et al.,

2009) inventory new product possibilities, together with the processes, technological lock-ins and alliances between sectors or knowledge bases required to achieve production of the molecules.

3.2.6. Public policies for the bioeconomy

Backcasting projects (see sub-section 3.2.5.) were launched between 1999 and 2012. They defined biorefinery models, promising biorefinery products, knowledge bases to use, and actors who should be part of the biorefinery. Then, in 2012, the European commission first used the word "bioeconomy", translating a combination of KBBE and biorefinery policies. The policy was no longer biotechnology driven but became "mission-driven", with the biorefinery as a core artefact.

To sustain the supply-side of the bioeconomy, public authorities used national or European calls for projects (like FP7 or H2020), also combining public and private funding. Leading players, including the European lobby for biotechnologies EuropaBio, the Italian firm Novamont, clusters such as "Industries & Agro-Resources Cluster", also came together in the Bioeconomy working group of the Standing Committee on Agricultural Research to support the of a Public-Private bioeconomy development partnership (SCAR, 2015).

The institutional answer to this has been the launch of a public-private partnership, the Bio-based Joint Undertaking (BBI-JU) (Carrez, 2017). Launched in 2014, BBI-JU funding is 1/3 public (€975 million from the EU) and 2/3 private (€2.7 billion). BBI-JU calls for projects are based on the definition of five value-chains (SIRA, 2013), for which it is possible to link a group of leading players. For each of these value-chains, the goal is to fund a flagship project. Rather than simply defining a typology of value-chains, BBI-JU aims to produce shared resources, for two reasons. First, as it is mainly funded by the private sector, its mechanisms are based on calls for research to develop parts of value chains. In practice, shared resources mean shared uncertainty. Second, even if BBI-JU aims to develop pilot and demonstration plants, some research topics involve pure research and SME funding. This type of funding will be used to consolidate knowledge bases grounding the value chain types.

3.2.7. Market and user practices in the bioeconomy

Statistics show that the bioeconomy turnover was of €2.2 trillion in 2014 (Ronzon et al., 2017). In 2014, most of the turnover in the bioeconomy came from "traditional bioeconomy sectors," i.e. agro-industries (€1.52 trillion), wood and paper industries (€0.42 trillion), biobased textiles (€0.11 trillion), and fishery and aquaculture (€0.01 trillion). In the same year, biobased chemicals, pharmaceuticals and rubber provided €0.13 trillion of turnover, liquid biofuels €0.03 trillion, and biobased electricity €0.01 trillion. The bioeconomy also has different markets from biotechnology because of the issue of identifying a substitution strategy between drop-in products and products with novel functionalities.

To sustain the development of biobased product markets, industries are expecting a European programme for public procurement of biobased products, following the American example (SCAR, 2015). But such a programme requires a clear definition of what a biobased product is. The USA has defined a norm that considers the product's biobased carbon content, encouraging drop-in substitution. This norm was somewhat controversial in Europe. Under the pressure of agro-industries, the norm has been widened to other biomass compounds, such as water and hydrogen.

4. Discussion

4.1. Differences and links between biotechnology and the bioeconomy

The following table (table 1) summarizes the results presented in section 3. The table shows clear differences between biotechnology and the bioeconomy. Whereas biotechnology is technology-driven (even in the OECD definition), the bioeconomy is biomass-centred and conveys expectations of sustainability. The biorefinery dominates the bioeconomy, acting as a unifying artefact (Hausknost et al., 2017; Levidow et al., 2018). Nevertheless, an opposing view of the biorefinery-based bioeconomy, focusing on the sustainable use of biomass, claims that the bioeconomy acts as a lever for transition (Vivien et al., 2019).

The second difference lies in the knowledge bases. The biotechnology industry knowledge base is unified and homogeneous. On the contrary, the bioeconomy knowledge base is heterogeneous, which has two consequences. First, competition is strong between different technologies. Second, some organisations, such as pilot and demonstration plants, have emerged to deal with this knowledge heterogeneity (Hellsmark et al., 2016; Antonelli, 2006).

Finally, the actors involved are quite different. Biotechnology is specialised, with incumbents developing biotechnology processes in alliance with start-ups. In the bioeconomy, the principal players are incumbents from agro-industry and the pulp and paper industry, which are biomass-centred. These players are becoming interested in white biotechnology processes, among others, which are not yet scalable for industrial processes.

It appears clear that biotechnology and bioeconomy are not the same, and that the bioeconomy cannot be considered as a subsector of biotechnology industry. Since biotechnology is part of the emerging bioeconomy knowledge base, the biotechnology industry is one of several sectors supplying technology (chemical industry, agro-industry and wood industry). So, biotechnology is incorporated into the production process and can be combined with processes from other disciplines. For example, the production process for the biodegradable plastic PLA combines fermentation processes with typical chemical transformation process.

Table 2: The biotechnology and the bioeconomy as sociotechnical regimes

	Biotechnology	**Bioeconomy**
Cultural and symbolic meanings	- New industrial revolution - Schumpeterian entrepreneur	- A 'great transition' toward the sustainable use of renewable resources - Aimed at mitigating and adapting to climate change, creating rural jobs, managing sustainable resources, ensuring food security, reducing dependence on non-renewable resources and maintaining competitiveness in Europe
Guiding principles	- Technology driven - Spreading biotechnology into health, food, industry, etc. - Industrialization of the living	- Mission-driven towards the substitution of biomass for oil - Constraints of economic and potentially environmental sustainability - Drop-in products (copying petrochemistry) *vs.* new functions products
Knowledge bases	- Fermentation and synthetic biology	Four knowledge bases: thermochemistry, biotechnology, oil-based chemistry, mechanical processes
Technology, infrastructures, artefacts	- Patents and start-ups as core artefacts - Markets for technology	- Biorefinery, products and inputs as core artefacts - Pilot and demonstration plants as value-chain coordination infrastructure - Backcasting as social technology to define visions for the future - National roadmaps toward bioeconomy - Review articles
Industrial structure, networks	- Duality between start-ups and incumbents - Development of alliances - Public-private networks	- Incumbents in agro-industries, pulp and paper, biotechnology and chemical industries - Public-private partnership to finance scaling-up - Biotechnology start-ups
Policy and regulations	- Technology-driven policy - Knowledge commoditization and financialization - Biotechnology as a Key Enabling Technology	- Mission-driven towards the substitution of biomass for oil policy - Backcasting to identify desirable futures for bioeconomy thanks to product identification - PPP to support scale-up of industrial processes - Call for projects to coordinate actors
User relations and markets	- Economy of promises: investments driven by breakthrough promises	- Competition between knowledge base promoters, between biomass and products (drop-in *vs.* novel functionalities strategies) - Cooperation within value-chains in research programmes or pilot and demonstration plants

4.2. Which policy for which bioeconomy?

As stated in the literature review, regimes are only semi-stable configurations. This is particularly true of the bioeconomy, since it is an emerging field. Nevertheless, biotechnology and the bioeconomy have their own logic, paving the way for three policy-mix options (Rogge and Reichardt, 2016), depending on how one formulates the problems to solve and the objectives to reach, as presented in the previous section (Borras and Edquist, 2013; Mazzucato, 2018). I sketch three policy-mix options below (summarized in table 3). They should be considered as ideal-types and open for discussion.

4.2.1. The bioeconomy thanks to biotechnology

The first policy-mix option, the "biotechnology bioeconomy", would aim to solve growth issues thanks to biotechnology innovation. Public investment should support both R&D and the industrialization of white biotechnology processes, and green biotechnology for agriculture. These investments should also be directed towards biology and biotechnology training and education. Firms should be encouraged to adopt biotechnology in their production process, creating markets for biotechnology processes. Moreover, GMO regulations should be dismantled to sustain the development of biotechnology-dedicated crops. To foster interactions between start-ups and potential biotechnology clients, specific organizations should be developed to tackle the IP issues specific to life sciences (OECD, 2012). For example, multisided organizations could provide incumbents with access to new (potentially unpatented) knowledge produced by start-ups. The revenue model of such organizations could also depend on the level of maturity of technologies, with incentives provided for promising low-maturity technologies to take the risk of radical innovation.

4.2.2. The bioeconomy thanks to the biorefinery

The second policy-mix option, the "biorefinery bioeconomy", would aim to ensure the transition toward the use of renewable resources in biorefineries and make it economically sustainable. In this mix, sustainability as such is not the goal of the policy, but may be a goal to reach or a contingency. This policy mix should focus on unifying knowledge bases (see 3.2.3.) to stabilise innovation process. To do so, investments in multidisciplinary training and research projects would help shape the knowledge base of the bioeconomy (Lewandowski et al., 2018). To offer the maximum possible innovation opportunity, niche technology diversity should be preserved (Kivimaa and Kern, 2016). To develop markets for biobased products, three types of markets should be developed. First, mass markets (e.g. energy) could be targeted, especially boosted by public procurement (Costantini et al., 2015; Edquist and Zabala-Iturriagagoitia, 2012). Second, quality labels could be developed to offer opportunities to differentiate biobased products. Third, high value applications could be developed to compete with high value additives with new functions (e.g. biodegradability or improved chemical properties). These market development strategies should be linked with improved pilot and demonstration plants or innovation intermediaries (Hellsmark et al., 2016; Kivimaa et al., 2019), also oriented towards entrepreneurship, and offering small-scale high-value production opportunities. The development of such a bioeconomy raises the issue of its economic and sustainability monitoring (Espinoza Pérez et al., 2017).

4.2.3. The sustainable bioeconomy

The third policy-mix option, "the sustainable bioeconomy", would aim to transform production and consumer systems using biomass, *i.e.* act as a transition lever. The overarching idea of this policy option is the limited availability of biomass and the sustainability of its cultivation, which need to be monitored to develop sustainable production systems. To cope with this strong constraint, the guiding principle of this policy would be creative destruction and niche support for "functional substitution" instead of drop-in substitution (Kivimaa and Kern, 2016). "Functional substitution" takes a broader view of products than drop-in substitution: products are considered in light of the functions they offer. Hence, the goal is to offer the same functions, but more sustainably. For example, in the case of transportation, the issue may be the substitution of biofuel for fossil oil-based fuels, which is unsustainable (Giampietro and Mayumi, 2015), or simply moving from point A to point B. Then, in the case of functional substitution, the question is no longer one of retaining private vehicles, but of satisfying the need for mobility. Hence, the issue is not one of determining the best technological option to process biomass, but of making the right organisational choice (e.g., public transport systems) that may use a variety of sustainable technologies. This means that biomass-based options may be combined with other technologies (electric systems, etc.). Moreover, besides this niche diversity-preservation strategy, this bioeconomy would direct the selective pressure towards the most sustainable options.

To do so, it would be necessary to invest in multidisciplinary training and research promoting sustainable approaches, to unify the bioeconomy knowledge base. The selection of these research programs would be oriented by assessment tools using life cycle analysis, metabolism analysis, etc. Moreover, these tools would be used to monitor the sustainability of the bioeconomy. In this way, circularity should be a constraint rather than a justification for production. Labels might be a useful way to organise competition and inform the demand side. Labels signal product quality, in this case, product sustainability. Nevertheless, the cost of certification cost may hinder the adoption of labels. Therefore, taxes on unsustainable products could fund label adoption and promote sustainable products. Alternatively, “unsustainability labels” could be developed, which unsustainable products would have to display. Besides this, public procurement would also sustain the development of sustainable biobased product demand. To achieve this view of the bioeconomy, investment would be needed in organizational innovation to develop sustainable production and biomass supplies.

Table 3: The policy-mix options for the bioeconomy

	The bioeconomy thanks to biotechnology	**Bioeconomy of biomass**	
		The bioeconomy thanks to the biorefinery	**The sustainable bioeconomy**
Function of the bioeconomy	Subsector of the biotechnology industry	New sector, green growth	Transition to sustainability lever
Types of policy	Technology-driven	Niche support	Creative destruction and niche support
Knowledge base	Biotechnology, only needs reinforcement	Unification of the knowledge base under the constraint of biomass use	Unification of the knowledge base under constraint of sustainable biomass use
Types of substitution	Process substitution by biotechnology processes. Types of products is not an issue	Drop-in substitution / functional substitution in the case of high-value products	Functional substitution
Policy tools	- Supporting R&D and biology industrialization - Supporting training and education in biotechnology - Supporting firms adopting biotechnology processes - Multisided markets as dedicated biotechnology markets - Supporting low maturity technology	- Multidisciplinary training and research - Preservation of niche diversity - Markets development: public procurement, quality labels, support for high-value products - Developing innovation intermediaries and pilot and demonstration plants - Indicators to specifically economic performance of the bioeconomy	- Supports for innovative sustainable organisations - Implementation of sustainability evaluation criteria - Multidisciplinary training and research to favour sustainable production - Sustainability/unsustainability Labels - Public procurement for sustainable biobased products - Support for intermediaries developing sustainable organisational and technological innovations - Support for sustainable biomass production
Sustainability	Weak	Depends on product type	Strong

5. Conclusion

This paper starts by identifying two main definitions of the bioeconomy. The first centres on biotechnology and the second on biomass and the artefact of the so-called biorefinery. However, the literature has never studied their links and differences as sociotechnical regimes. This paper endeavours to fill this gap, highlighting the fact that biotechnology and bioeconomy differ in terms of knowledge, institutions and actors. The biomass bioeconomy differs from biotechnology with its heterogeneous knowledge base, its main institutions (biorefinery, pilot and demonstrations plants, technological roadmaps) and actors (agro-industries, pulp and paper industry, and the chemical industry, together with some biotechnology players). Hence, biotechnology is a small part of the bioeconomy, mostly as a technology provider. Finally, because of the strong sustainability expectations of the biomass bioeconomy, we sketch out three possible policy-mixes: once promoting biotechnology for growth, one promoting green growth through biorefineries, and one promoting sustainable transition through the bioeconomy. Each of these policy mixes takes its own approach to sustainability, depending on the missions given to the bioeconomy.

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Biography

Nicolas Befort holds a PhD in economics from the University of Reims. His doctoral research was dedicated to the emergence of the bioeconomy. After a postdoc at the Laboratory of Economics of the University of Orléans, he has been appointed as tenured Assistant Professor of Economics at NEOMA Business School (France). At NEOMA Business School, he is member of the Chair in

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