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Methodological and Ideological Options

The Hijacking of the Bioeconomy☆

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ABSTRACT

Georgescu-Roegen used the term bioeconomy to refer to a radical ecological perspective on economics he developed in the 1970s and 1980s. In recent years, it has also become a buzzword used by public institutions to announce and describe a supposed current economic and ecological transition. We see in this use an attempt of semantic hijacking of the original term. To support this claim we analyze three different interpretations of the term bioeconomy, presenting each of them as narratives combining distinct visions of future economic development, technical trajectories and imaginaries associated with a particular relationship to nature. Finally, we discuss these narratives in relation to the endorsement they receive by different stakeholders.

1. Introduction

The term "bioeconomy" is one of those contemporary expressions that crop up regularly at the crossroads between socio-economic and environmental dynamics. Various authors and institutions have used it in recent years to describe a new economic sector organized around industrial activities that both complement each other and compete for access to biomass (OECD, 2009; EC, 2012; OECD, 2017a). Attaching the prefix "bio" to the term "economy" implies that this emerging sector works to bring economics and ecology together to achieve sustainable development.

Obviously, ecological economists cannot remain indifferent to this term, or to the reality it encompasses. They are bound to be interested in anything that might indicate that an ecological transition is underway. Moreover, they know that the term "bioeconomics" refers to a theoretical perspective developed by Nicholas Georgescu-Roegen in the 1970s and 1980s, which has influenced—and continues to influence—the teaching, structure and discussion of Ecological Economics through the idea of "de-growth" (Martinez-Alier et al., 2010). The question that immediately springs to an ecological economist's mind when encountering the term "bioeconomy" is about its meaning, since several conflicting conceptions of the term are found in literature (Bauer, 2018; Bugge et al., 2016; McCormick and Kautto, 2013).

To clarify this issue, we adopt a narrative approach (Giampietro and Ramos-Martin, 2005; Hajer and Versteeg, 2005; Franceschini and Pansera, 2015; Saltelli and Giampietro, 2017) studying the different meanings of the term in relation to the narratives associated with it. In Section 2, we explain our theoretical framework and methodology. In Section 3, we present the three main narratives we have identified in this controversial field: Georgescu-Roegen's idea of the bioeconomy sense[1] (type I bioeconomy), the bioeconomy as industrial promises offered by the biotechnology revolution (type II bioeconomy), and the bioeconomy as a bio-based carbon economy (type III bioeconomy). Section 4 compares and discusses these three types of bioeconomy. While the first narrative about bioeconomy acknowledges the significant material and energy limits that growth will inevitably encounter, the other two call for an industrial mobilization of biomass to continue pursuing economic growth, which will eventually turn "green." Is the use of the term bioeconomy in these two narratives is a semantic appropriation—a kind of conceptual hijacking—of the original term "bioeconomy," as theorized by Georgescu-Roegen?

In seeking to answer this question, our aim is for ecological

☆ The views expressed in this article are the authors' own. This article is dedicated to Martino Nieddu, who died suddenly in June 2018. We owe a great deal to him.

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[1] Georgescu-Roegen uses the term "bioeconomics" in his work to mean a new discipline running counter to the economics he had learned at Harvard. However, this new type of economic analysis led to discussions and recommendations—particularly in the area of energy technologies—that come under what is now called the bioeconomy. This is why we feel justified in speaking of a "bioeconomy" in Georgescu-Roegen's sense.

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Table 1
Framework summary.

Definition	How is the bioeconomy defined?
Nature-economy relations	How are the relations between economic and natural systems and resources theorized?
Socio-technical relations	Which role does the representation of the bioeconomy give to innovation and technical change?
Governance	How should the transition towards the bioeconomy be organized?
Sustainability	Strong or weak sustainability?
Tensions and paradoxes	What are the main paradoxes arising from the vision promoted and tension between competing actors?

economists to reclaim the subject and the debate surrounding the bioeconomy. It is strange, to say the least, that the subject and subsequent debate, which first emerged within the ecological economics movement through the work of Georgescu-Roegen, are now practically absent from the journal *Ecological Economics* (Asada and Stern, 2018; Bais et al., 2015; Baka and Bailis, 2014).

2. Framework and Methodology

2.1. Framework

Our approach draws upon "classical institutional economics" (Vatn, 2017), applied to sustainability. Institutions are meant as formal and informal norms stabilizing coordination in society and providing stable expectations, that is guiding actors' choices (Beckert, 2016). This approach focuses not only on actors' relations and conflicts but also on interactions between economic and ecological systems. Actors have two main features: (i) they have conflicting values, raising governance issues, and (ii) they have purposes, that is their action is future-oriented (Dupuy et al., 2015).

First, conflict animates actors' relations because of their diverging interests. These conflicts are the source of institutional change. In the dynamic of institutional change caused by the development of the bioeconomy, actors try to take control and dominate their field in line with their expectations (Jullien and Smith, 2011). In an emergent field, by creating shared views among actors (scientists, industries, governments), they will lead to resource (re)allocation and the development of new institutions, shaping socio-technical relations (Beckert, 2016). These resources may be reallocated towards the production of strategic vision documents, the funding of research programs, investment, or training (Langeveld et al., 2010).

Expectations take the form of narratives embedded in the aforementioned artefacts. These narratives are forms of action in the world, involving power relations (Franceschini and Pansera, 2015; Saltelli and Giampietro, 2017). Hence, they need to be treated as a part of the "material reality" of economic systems, i.e. involving power relations, socio-technical imaginaries, and relations with the environment and natural resources (Giampietro and Ramos-Martin, 2005; Giampietro and Mayumi, 2009). Studying narratives provides a sound approach to highlight the strategies developed by the main actors to take control of their field (Franceschini and Pansera, 2015).

Following this framework, our aim is not to produce another literature review on the definition of the bioeconomy (see Bugge et al., 2016). Our starting point is the existence of competing approaches among bioeconomy stakeholders, which we identify them through their narratives. We consider narratives as the input to define *ideal-types* of bioeconomy visions linked to actors' strategies. The following table (Table 1) summarizes our framework.

2.2. Methodology

The promises and expectations that the narratives convey are based on a combination of elements: scientific theories, conceptions of the economy and society, data and technical imaginaries, and representations of nature and the relations we should have with it. This paper is part of a French research program called "Bioeconomy in Champagne-Ardenne" (PSDR 4), launched in 2016, which follows on from a first research program[2] dedicated to the development of the so-called bio-based chemistry. These programs are based on a collaboration between economists, chemists, and life science researchers. We collected three types of data.

First, we began a scientific watch on the topic of the bioeconomy and the non-food use of biomass in 2012, for a former research program. This was coupled with a literature review of publications in social sciences, engineering, chemistry, life science, and public policies. We selected publications defining what the bioeconomy should be, which technologies should be used, how it should be organized and governed and the sustainability issues involved. The scientific publications came from the social sciences (including *Sustainability*; *Biobased and Applied Economics*; *Resources*), chemistry, and biotechnology (including *New Biotechnology*; *Biofuels, Bioproducts and Biorefining*; *Green Chemistry*). The reports we used were mainly produced by public institutions (European Commission, OECD), semi-public organizations (Biobased Industry Consortium, NNFC), publicly funded research projects (StarProBio, BiorefineryEuroview, Biocore, Suprabio) or national public bodies (VTT in Finland, INRA in France, etc.). We regularly reviewed our results and discussed them with project members who were chemistry and life science researchers.

Second, we conducted semi-directive interviews with 23 stakeholders (at least two interviews with each member) between 2016 and 2018. These interviews lasted between 45 and 120 min. Interviewees included chemists and biotechnologists (researchers and engineers), consultants, industry representatives, social science researchers and public authorities. The interview guide covered the topics identified in our framework: nature-economy relations, socio-technical relations, governance, and sustainability. We recorded the interviews (when possible, due to confidentiality issues). We asked feedback questions to clarify answers during follow-up meetings or by email.

Third, we used participant observation, attending twelve bioeconomy conferences (organized by either public bodies or industry associations), five national and seven European. We produced reports on these, which we discussed between project members.

Finally, to test the consistency of our ideal-types of bioeconomy narratives, we presented them to bioeconomy stakeholders at several seminars.

3. Bioeconomy: Three Main Narratives

Our goal is not to offer an exhaustive view of bioeconomy narratives, but to describe and characterize ideal-types of bioeconomy visions.

3.1. Type I bioeconomy: Considering the Limits of the Biosphere

As Gordon (1954) recalls, the term "bio-economics" was coined in the 1920s by Russian biologist Baranoff (1918, 1925) to describe fishery economics. After the development of the Gordon-Schaeffer model in the 1950s (Clark, 1976), the term bioeconomics gradually

[2] National Research Agency program "An Economic Approach to the Integration of socio-economic and technological dimensions in Doubly Green Chemistry Research Programs" (ANR-09-CP2D-01-01 AEPRC2V).

spread to include all renewable resource economics, as these resources were coming under increasing pressure and the first attempts at regulation were being undertaken, particularly with regard to fisheries. The ideal of this field of research at the crossroads of economics and ecology is to establish the "maximum sustainable yield", that is to determine the quantity of a biological resource that can be exploited without threatening its capacity to reproduce. If we think about "natural capital" as a whole, this is one possible definition of sustainability, as understood in ecological economics (Costanza and Daly, 1992).

When Georgescu-Roegen (1975a) first used the term "bioeconomics," he gave it a different meaning. At this time, he was involved in the controversy following the first report to the Club of Rome (Meadows et al., 1972), siding with Dennis Meadows in response to criticism by conventional economists favorable to the pursuit of growth (Levallois, 2010). For Georgescu-Roegen, the term bioeconomics signifies the particular problem of survival the human species faces. Like any living being, man has to struggle against the law of entropy. But, in line with philosopher Henri Bergson, biologist Alfred Lotka and Joseph Schumpeter, whom he considered his economics mentor, Georgescu-Roegen points out that the biological—or "endosomatic"—evolution of the human species has continued on the technical—or "exosomatic"—level. Technology, he explains, prolongs man's biological body, allowing him to extend his field of action: thanks to the plane, he is able to fly *like* a bird; thanks to the submersible, he is able to dive, *like* certain marine animals, to very great depths. Therefore, argues Georgescu-Roegen, if man wants to live and develop, he must not only seek low entropy for his metabolism, he must also look to maintain the matter and energy flows required for the operations of the technical objects that surround him (Georgescu-Roegen, 1975a).

Georgescu-Roegen (1978) stresses the notion of "Promethean technology," referring to the particular class of technologies that, thanks to both qualitative and quantitative technological leaps, make abundant amounts of energy accessible to humanity and induce very long-term techno-economic cycles. According to Georgescu-Roegen, "Prometheus I" – the control of fire by early humans - named after the titan who stole it from the Gods in Greek mythology, was succeeded in the eighteenth century by "Prometheus II": Thomas Savery and Thomas Newcomen, the inventors of the steam engine. The Age of Wood thus gave way to the Age of Coal. Since the advent of this "thermo-industrial revolution"—here Georgescu-Roegen (1978) takes up Jacques Grinevald's concept—we have seen low-density low-entropy biological sources replaced by high-density low-entropy fossil sources. Yet while this transition has released tremendous amounts of energy powering human agency, it has led humanity to face serious ecological limits through the depletion of fossil fuels and the disruption of major biogeochemical cycles.

In the long run, according to Georgescu-Roegen, another transition will be unavoidable, and it may or may not involve the advent of "Prometheus III" (see Fig. 1). In the 1970s and 1980s, he became interested in solar energy and introduced the difference between "feasible" and "viable" technologies associated with the definition of the minimum level of net productivity achievable when exploiting alternative energy sources. Georgescu-Roegen (1986a,b) even spoke of a possible "new Wood Age". But, while awaiting the arrival of this new Prometheus, we should exercise caution by saving finite stocks of fossil resources as much as possible, using them to meet only the most urgent needs—particularly those of populations living in the South. Hence, Georgescu-Roegen introduced the prospect of "degrowth" through the establishment of a "minimal bioeconomic programme" advocating, among other things, the implementation of agriculture (Martinez-Alier, 1997), the fight against waste, and a quest for "sufficiency" by consumers.

3.2. Type II bioeconomy: A Science-based Bioeconomy

The second meaning of the term bioeconomy is a science-based vision of development in which "*biotechnology is the core lever of the bioeconomy*" (Patermann and Aguilar, 2018, p. 22). It gradually emerged during the 1990s and 2000s in reference to the "biotechnology revolution" of recent decades. This revolution relies on the expansion of traditional fermentation biotechnology to genetic manipulation (Bud, 1991). The movement originated in the discovery of the double helix structure of DNA in 1953, the regulation of protein synthesis in 1961, and the isolation of genes in 1969. Very quickly, this expansion was presented as both a paradigmatic revolution built on a new knowledge base, and as an industrial revolution for pharmacy, medicine, agronomy and chemistry, through the constitution of biotechnologies as general-purpose technology (McKelvey, 2007).

To fulfil this potential, public policy has encouraged research programs to shape the prospect of a knowledge economy (Patermann and Aguilar, 2018; Philp, 2018). This is reflected in the intense efforts by major intergovernmental organizations to define and redefine the issues semantically. The "knowledge economy," which was advocated in an OECD report (1996) emphasizing the promises and dangers of biotechnology, was thus renamed "Knowledge-based economy" (KBE) in the 1990s (OECD, 1998). A new semantic shift took place in 2005 with the invention of the expression "Knowledge bio-based economy" (EC, 2005). It specified an R&D agenda in which the dominant vision relies on the use of biotechnology in agriculture, fisheries, and the wood industry (Aguilar et al., 2009; Levidow et al., 2012). This was followed some years later by the expression "bioeconomy" in the 2009 OECD report, which continued to draw decision-makers' attention to the conclusions to be drawn with regard to fostering biological industrialization through public policy (NRC, 2015).

This perspective, shaped largely by the OECD (1998), takes us back to Schumpeter's representation of industrial revolutions as resulting from a core of scientific advances spreading in innovation clusters through a series of economic and social areas. According to this view, as scientific breakthroughs in biotech form a system (on genomes, cellular processes and bioinformatics), they are liable to produce a life science-based industrial revolution (see Fig. 2).

As it deemed this future science and technology paradigm indisputable – it was a classic example of "Socio-Technical Imaginaries" (Jasanoff and Kim, 2015) – the OECD considered it essential to resolve the issues of resistance to change, speed of innovation diffusion, and resource reallocation towards the new paradigm. Specific support was needed, given that the promises of biotechnological processes face competition from other processes with other scientific bases, which may prove more economical. This bioeconomy relies on the introduction of new forms of organization in OECD countries (Mowery and Sampat, 2005; OECD, 2017a,b,c): knowledge commoditization (Birch, 2017) through patents (Krauss and Kuttenkeuler, 2018), strategy financialization (Festel et al., 2012) and the development of alliances and joint ventures (Powell et al., 1996).

The development of this institutional architecture led to the structuring of two types of networks (Belussi, 2016). First, start-ups are associated with the heroic figure of the Schumpeterian entrepreneur making a scientific breakthrough that offers techno-scientific promises, thereby gaining both private venture capital and public funding. But these firms do not possess all the technological and organizational expertise required to market their products or to scale up their production (Mustar et al., 2008). Second, as knowledge is a complementary, idiosyncratic resource, and dedicated biotechnology firms (DBFs) lack capabilities, they need to develop alliances with existing pharmaceutical firms (joint ventures, financial holdings or acquisition) and universities (Belussi, 2016; Festel et al., 2012).

3.3. Type III bioeconomy: A Biomass-based Bioeconomy

The third meaning of "bioeconomy" currently dominates, in European Union at least. The European Commission has used it since 2010 to encompass the agriculture, forestry, fishing, chemistry,

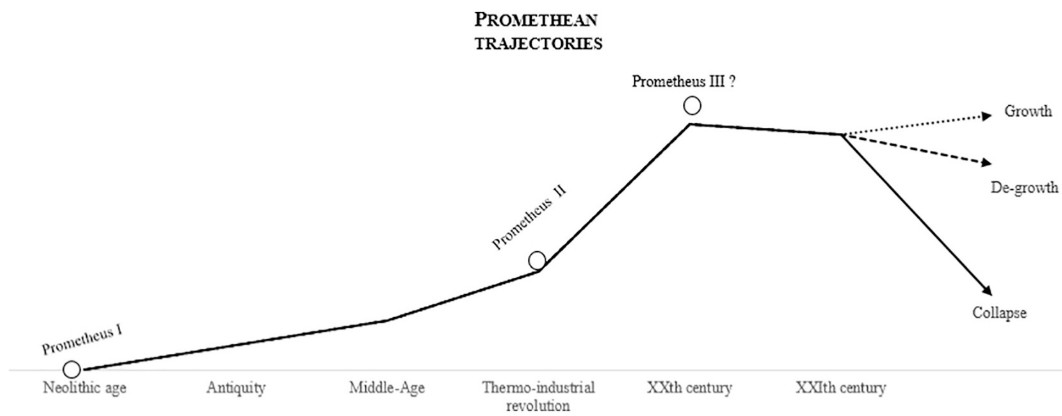

Fig. 1. Type I bioeconomy.
For Georgescu-Roegen, as for Schumpeter, technological innovations are unpredictable. We do not know *when* or even *if* Prometheus III will appear. Hence various possible scenarios: at the two extremes, either a return to growth or a collapse of economic and social dynamics is possible. The middle scenario, which Georgescu-Roegen seems to have preferred, is to choose a form of degrowth to manage the waiting period and devote available resources to meeting the most urgent needs of the poorest populations.

biotechnology and energy sectors, the raw materials of which the Commission advocates should be transformed in "biorefineries" (EC, 2012). Biorefineries are defined as complex systems based on the economically and environmentally sustainable transformation of various types of biomass (wood, agricultural products, waste, and algae). Biorefining is also a concept designed to frame the transition towards the use of biomass to replace fossil resources (Kamm et al., 2010).

The shaping of the biorefinery concept is the product of an institutional project (Tukiainen and Granqvist, 2016) with a long history. In the 1930s, the "chemurgy" movement aimed to turn agriculture into a supplier of carbon raw materials for the chemical sector (Finlay, 2003). At the time of the Great Depression, the arguments for this hinged on the use of agricultural surpluses and the need to create jobs. The prospect of connecting the agricultural and chemical sectors was the subject of renewed interest in the 1970s, with rising oil prices and agricultural surpluses resulting from the success of the Common Agricultural Policy, implemented in Europe in the 1960s. Farmers sought to turn the non-food share of their production to profit in the fields of biofuels and bioproducts. Socio-environmental issues, which were not present in the early 1980s, gradually appeared as both constraints and development opportunities. This resulted in plant refineries being renamed "biorefineries", the prefix "bio" being a means to denote both the origin of the carbon and plant resources treated there, and the hopes attached to these technologies in terms of ecological transition. Thus, the type 3 bioeconomy is not "technology-driven" like type 2, but "biomass-oriented," that is, oriented by the aim of ensuring transition to an economically viable use of biomass. However, it is not sure that this transition will result ecologically sustainable. Its vision of development borrows heavily from the multi-level perspective (Langeveld et al., 2010; Geels, 2004) (see Fig. 3). It also belongs to the class of Socio-Technical Imaginaries mentioned earlier (Jasanoff and Kim, 2015).

This exploration of new opportunities was structured through foresight exercises and technological roadmaps in North America and Europe (the *BIOPOL* and *BIOREFINERY Euroview* projects) involving mainly agribusiness and the wood and paper industries. These back-casting exercises aimed to inventory available raw materials and knowledge bases to mobilize, structuring stakeholders' communities (Staffas et al., 2013). As they were searching for new growth sources to offset the saturation of their traditional markets, players involved pushed for the knowledge-based bioeconomy to encompass the transformation of biomass in the "biorefinery". Hence, the type III bioeconomy is united in its attempt to transform biomass from various sources. To deal with this heterogeneous knowledge base, players use pilot and demonstration plants to determine possible bridging technologies and assess their maturity in line with the "Technological Readiness Scale".

Two strategies compete for fossil resource substitution within this ensemble (Cherubini et al., 2009; de Jong et al., 2012). The first, the so-called "drop-in" strategy, aims to enter mature, established, well-identified fossil fuel-based markets rapidly. In this case, biorefining is designed to do the same job as traditional petroleum refining, namely cracking operations, and then purifying a small number of chemical intermediates to produce the same platform molecules for target products in the chemical commodity market (SCAR, 2015, p. 64). This strategy of raw biomass fractionation, which is interested in biomass only as a supplier of carbon chains, can take two different technological pathways. The first is based on thermal deconstruction, using long-established gasification or methanation processes to produce syngas. The second is that taken by biotechnology biorefining players, who are also keen to explore all the possible replacements for petro-chemistry processes. The second substitution strategy followed in biorefining favors the identification of expected functions (producing biodegradable, lighter materials, etc.) and the production of new products, rather than

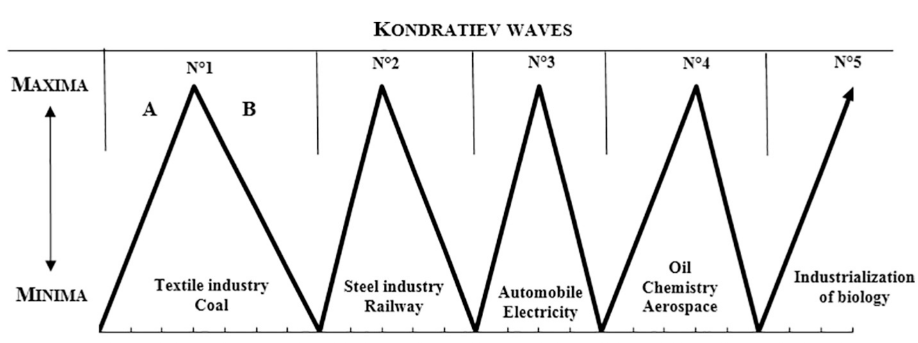

Fig. 2. Type II bioeconomy.
The type II bioeconomy fits Schumpeter's theory of long Kondratiev-type cycles. By the end of the 1960s, the industrialization of biology was seen as a coming industrial revolution, i.e. a fifth Kondratiev wave. But the promises of biotechnology have been slow to materialize in a new innovation cycle, and have led to extensive institutional efforts by the OECD, reflected in its references to the bioeconomy since the late 2000s.

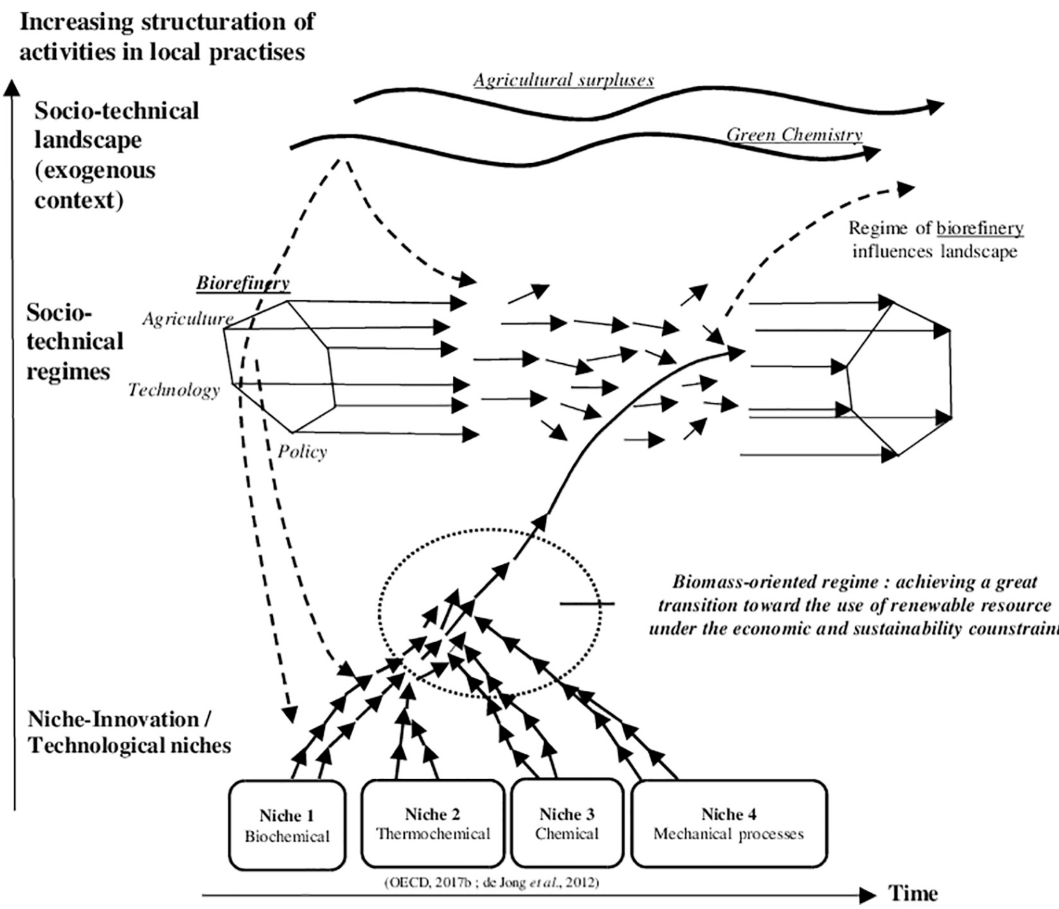

Fig. 3. Type III bioeconomy.
The type III bioeconomy is consistent with the multi-level perspective (figure adapted from Geels, 2004). Due to pressure from the "landscape" (structural agricultural surpluses, the chemical sustainability problem, the search for new outlets for the paper industry), stakeholders re-explore old knowledge, either biotechnologies or modern chemical techniques (esterification, catalysis, etc.). The exploration of technological trajectories within four large "niches" should, after an industrialization phase in biorefineries, lead to the formation of a new socio-technical regime driven by the twofold constraint of economic and environmental sustainability on the use of renewable resources.

an identical substitution approach (for example, replacing a fossil-based PE plastic with a bio-based polyethylene). This second substitution strategy does not consider organic matter simply as an undifferentiated carbon source but seeks to preserve its complexity to foster innovation.

Because the products being developed are complex objects, it is difficult to assess their sustainability. Following the controversy surrounding agrofuels regarding their carbon footprint and competition with food production over land use, stakeholders are calling for the definition of common sustainability criteria, for adopting a cascading approach and including circular economy conceptions (Hansen et al., 2016; Espinoza Pérez et al., 2017; SCAR, 2015; Sokka et al., 2015; Falcone and Imbert, 2018).

4. Discussion

How to characterize the different types of bioeconomies discussed so far? Here, we discuss the different semantic attributes (Table 2) in relation to the items identified in Table 1.

4.1. Nature/Economy Relations

First of all, let's consider the meaning of the words used. The Greek prefix "bio-" is semantically very rich. It is open to multiple representations and interpretations of life and the living. Type I bioeconomy considers the complexity of the concept of life at a large scale. The economic process is viewed as a process of macroevolution whose adaptive potential must be preserved in the long term. Undoubtedly, in its long history, humanity has expressed unique features in relation to the other living species, however, when considering the big picture the expression of its biophysical metabolism remains restricted by the limits determined by the biosphere. On the contrary, type II bioeconomy considers only a specific aspect of life from a molecular perspective. By focusing only on the activities of production, it reduces it to its infinitely minute physical-chemical dimensions, i.e. to a series of elementary building bricks of life that can be rearranged by human skills. It focuses on knowledge of the genome and on the technical capacities required to modify it and it assumes that a boost in the productivity of a set of technical processes in the productive sectors of the economy will be able to solve all the problems of sustainability of human societies. Type III bioeconomy considers life from the angle of available biomass, that is, the mass of organisms it comprises at any given moment within existing ecosystems, or within the whole of the biosphere. However, this narrative considers biomass to be, "by default", as an amount of renewable natural resources that can be exploited at will. It does not consider the possibility that this exploitation may face both internal and external constraints – i.e. it does not consider the distinction between "available" and "accessible" resources proposed by Georgescu-Roegen.

4.2. Socio-technical Relations

Another semantic issue refers to the association that the term bioeconomy entails between economy, science, technology, and society.

Table 2
Summary of the three types of bioeconomy.

	Type I bioeconomy	Type II bioeconomy	Type III bioeconomy
Illustrative references	Georgescu-Roegen (1975a,b, 1978)	OECD (2009, 2017a,b,c)	Langeveld et al. (2010) EC (2012, 2018)
Definition	An ecological economy, that is compatible with the biosphere	A science-based economy driven by industrial biotechnology	A biomass-based economy
Nature/economy relations	Struggle against entropy and coevolution with the biosphere. Economic development in line with biological evolution	The cell is a factory Technology has the power to "correct God's mistakes"	Biomass replaces fossil fuels and mining to produce energy and materials
Science, technology and society	Megatrends with "promethean technologies" Pending the advent of Prometheus III, the economics of prudence and sharing	Prospect of a fifth Kondratiev wave based on the rise of biotechnology. The "economy of techno-scientific promises"	Biorefining at the heart of ecological transition (multi-level perspective). The economy of learning
Sustainability	"Strong sustainability" approach and degrowth perspective	Very "weak sustainability" approach	"Weak sustainability" approach
Governance	Democratic deliberation and ecological planning	Commodification of knowledge. Defense of intellectual property rights	Mission-driven policy - backcasting to identify desirable futures for the bioeconomy through product identification and stakeholder coordination
Tensions and paradoxes	Counter-expertise rather than concrete technical solutions Criticism from social groups who remain at the margins of decision-making centers Degrowth is not on the decision makers' agenda	Conflicts and competition in patenting but knowledge accumulation remains problematic How can biotech processes be integrated into complex multi-technological products? How can breakthrough promises be maintained as a one-best-way solution in all areas of application? Social resistance to GMOs	Substitution of products or functions by new products (chemicals and materials) Probably, increased pressure on resources and land

Type 1 bioeconomy, as theorized by Georgescu-Roegen, requires a holistic view considering a much longer timespan than the one on which Schumpeter and economists generally base their decision making. The concept of "promethean technologies" is not compatible with the concept of economic cycles, since we do not know *whether* a Prometheus III revolution will ever materialize, and in the affirmative, *when* it will take place. According to Georgescu-Roegen, the future will see unknown socioeconomic trajectories, and because of this uncertainty about the future the priority should lie in managing expectations of a possible bifurcation. This is why type I bioeconomy is an economy of prudence and why it involves sharing resources between generations and within our own generation.

Type II bioeconomy was born out of the slowdown in innovation in the pharmaceutical and chemical industries from the 1970s, among other reasons due to the failure of their main stakeholders to produce radical innovations, such as Nylon, to generate new cycles (Achilladelis et al., 1990). Type II bioeconomy is associated with the idea of Kondratiev type Schumpeterian cycles, in which the emergence of an optimal biotechnology would launch a new cycle of innovation and growth. This is why type II bioeconomy is a "technology-driven economy." In reality, it can also be called an "economy of promises" (Felt, 2007): promises to solve production and ecological problems thanks to technological breakthroughs enabled by genetic engineering. But the explanation of how the revolution in science and technology will translate into a revolution in the economy and the rest of the society is unclear.

Type III bioeconomy, promoted by the European Commission, is a renewable carbon economy based on biorefining, which aims to incorporate all types of biological resources into the process of biomass transformation. Since the same product can be manufactured using different raw materials and technologies, type III bioeconomy sets up a triple competition between raw materials used, processes selected from the range of existing trajectories, and products manufactured. Uncertainty and competition affect actors' strategies in two major ways. Firms may choose either drop-in/low-value strategies or innovative approach offering new functions in addition to their biosourcing: biodegradability, a longer lifecycle, better performance, etc. Second, the use of new raw materials requires the recombination of different knowledge bases, unlike type II bioeconomy, which is united around a body of biotechnological knowledge. Consequently, type III can be described as an economy of learning. This is manifested in the development of organizations dedicated to techno-economical study, such as pilot and demonstration plants (Fevolden et al., 2017; Hellsmark et al., 2016).

4.3. Sustainability

The question of the best sustainability model to adopt is at the heart of the debate over the bioeconomy and the transition it is expected to generate. How do the different types of bioeconomy position themselves with regard to the weak vs. strong sustainability debate (Costanza and Daly, 1992)?

Type I bioeconomy clearly belongs to the "strong sustainability" side. It describes an economy bound by very strict ecological constraints. As Georgescu-Roegen explained in his discussion of agriculture, the economy must consider both the agro-ecological conditions under which solar energy is transformed into biomass under the constraints of preservation of biodiversity. Similarly, he emphasized the energy and material limits of our recycling capacity. Degrowth, one possibility he envisages, even reverses the terms in which the problem of sustainability is generally presented. Rather than determining a trajectory that the economy and society could follow to enable long-term development, degrowth takes an opposite approach, which we might call a strategy for long-term survival. It is this "enlightened catastrophism," as Dupuy (2004) calls it, which makes type I bioeconomy an economy of prudence.

The two other types of bioeconomy belong to the "weak sustainability" side. This is particularly obvious in the case of type II bioeconomy, which ultimately aims to replace the components and mechanisms of the biosphere with others created by human ingenuity. This is nothing more nor less than the engineer's great dream of "recreating nature" to correct its failings. Synthetic biology equates biology and life with technology, and specifically the exploitation of living organisms by other living organisms, also opening biosecurity risks (Carlson, 2010). Similarly, the intensified use of these resources in the agricultural sector raises the problem of natural habitats being lost or modified due to anthropogenic pressures.

In the type III bioeconomy narrative, market signals are supposed to guide the change in socio-technical trajectory required for the ecological transition, adopting a "green" growth option. Hence, this third bioeconomy is probably a less radical project than type II, even though it claims to use biotechnology, among other technologies, to transform biomass. This means that type II and type III may merge. This particular alliance has been called "life science industry," in opposition to agro-ecological practices, paving the way for criticism of the type III bioeconomy (Levidow et al., 2013). Nevertheless, the focus on the use of biomass raises issues such as land use change, deforestation, intensification of pollution linked to agro-industries, etc. (Ramcilovic-Suominen and Pülzl, 2018). As mentioned earlier (Subsection 3.3), assessment of life cycles, feedstock available, etc., may be necessary. These tools also contribute to the narrative of the biomass-oriented bioeconomy to demonstrate its sustainability *ex post* (Falcone and Imbert, 2018). National and European roadmaps and action plans incorporate narratives about the potential for a circular bioeconomy, but which avoid the issue of the sustainability of such circular economy (EC, 2018; de Jesus and Mendonça, 2018).

4.4. Governance

These different interpretations of the future of the bioeconomy lead to different conceptions of the economic policies and instruments that will be needed to support it.

Type I bioeconomy promotes ecological planning (Georgescu-Roegen, 1975b), developed democratically, and implemented through regulation. This would impose ecological limits as part of a policy to redistribute wealth more equitably. When he drew up his minimal bioeconomic program, Georgescu-Roegen probably had in mind the international negotiations taking place at the time over the future of the Antarctic. The sixth continent was awarded joint world heritage status; its exploitation is not forbidden, but its resources can only be exploited in the name of humanity, and mechanisms must be set up to share these resources between the different countries in the international community. This approach is necessary not only from a technocratic perspective. In the 1970s, Georgescu-Roegen seems to have seriously considered seeking an alliance with environmental movements to implement his bioeconomic principles—this is the reason why some of his papers on "Economics and Entropy" were reprinted in *The Ecologist*. Ecological movements endorse his recommendations that we should act on demand rather than on supply, reduce consumption, and promote a standard of sufficiency.

Georgescu-Roegen opened up a new route for counter-expertise and public debate on production and development choices by developing a "feasible technology" approach, described using his unique conception of flows and funds. This approach has been taken up and expanded by a EU project MAGIC (magic-nexus.eu), which has applied relational analysis to his flow-fund model, obtaining a meta-analysis of the metabolic pattern of EU countries described as social-ecological systems, dubbed MUSIASEM. The resulting "quantitative story-telling" approach (Saltelli and Giampietro, 2017) has been applied, for instance, to denounce myths about the large-scale production of agro-fuels (Giampietro and Mayumi, 2009), and is currently used in MAGIC to check the robustness of existing biorefinery narratives.

The long-standing idea of liberating the productive potential of a new industrial revolution supported by biotechnologies, which is at the heart of the type II bioeconomy, has enjoyed intense institutional backing since the early 1970s, via national and international public policy. The future of this revolution is the subject of much scientific controversy. Particularly in Europe, social resistance remains strong to the production and use of genetically modified organisms and the economic logic (commodified knowledge, intellectual property rights, financialization, etc.) of the industrial stakeholders who intend to develop them (Levidow et al., 2013).

In the type III bioeconomy, actors have to deal with a heterogeneous knowledge base and a strong competitive environment. So they need tools to manage this complexity. Roadmaps and strategies define research agendas and priorities, mostly evaluated with the "Technological Readiness Level" (TRL) scale. Then, to cope with knowledge dispersion, stakeholders use dedicated coordination organizations such as pilot and demonstration plants or the public-private partnership connecting firms and knowledge producers.

4.5. Tension and Paradox

The bioeconomy is a highly contested field, in which type II and III bioeconomies dominate type I. Given the situation type I bioeconomy may appear as a counter-expertise rather than an ongoing economic policy agenda. That is, the narratives associated with type II and type III bioeconomies are explicitly challenged by the narrative of type I bioeconomy in relation to their weakness in relation to sustainability issues. Social actors concerned with the lack of sustainability of the present path of economic growth call for a "mission-driven" bioeconomy, to contribute to ecological transition using input substitution as a lever for the transformation of production and consumption modes. Accepting the claim of Georgescu-Roegen that energy and matter sources shape societies, we should move to new development strategies guided by strong sustainability rules based on accessible renewable inputs. On the other hand, incumbent chemical, agro-industry, and pulp and paper industry players prefer to consider the bioeconomy as a new sector. This new sector is expected to support industries in crisis, like agro-industries, offering new market opportunities. In this strategy of economic development, market signals will decide production orientation rather than sustainability. From the corporate perspective, this new sector will provide opportunities for greenwashing through the launch of products that including a small proportion of biomass but do not respond to global problems. For example, Coca-Cola has a strong interest in PEF, a perfect substitute for PET, which would accumulate with other plastics, but that would be no more than biobased.

5. Conclusion

The recent spread of the buzzword "bioeconomy" should not obscure the fact that this term has a long history, and has had several different meanings. We have shown that three main bioeconomy "narratives" now compete with each other. The actors who promote these different visions do not all have the same political weight nor the same political agenda. Driven by powerful lobbies, the third type of bioeconomy has become the dominant bioeconomy discourse, being more pragmatic than the other two, and claiming to incorporate them both. Biotechnology, which is central to the type II bioeconomy, is indeed one possible technological pathway for exploiting biomass. Furthermore, following the controversy surrounding the carbon footprint of agrofuels and their competition with food production over land use, the European Commission now intends to support the type III bioeconomy, assuming its environmental compatibility. In other words, the solution is seen as a "green" growth option. However, the use of the term "bioeconomy" in support of the hypothesis of a *perpetual economic green growth* can be seen as a semantic and conceptual hijacking of Georgescu-Roegen's term "bioeconomy". In this third bioeconomy narrative, the change in socio-technical trajectory required for the ecological transition is supposed to be delivered through market signals. As such, there is every indication that the economic stakeholders involved will favor the substitution of molecules in existing markets and well-established value chains. The dominant design and economic organization that the powerful stakeholders behind the type III bioeconomy are trying to establish will almost certainly mimic those of the petrochemical industry.

Of course, this hypothesis needs further work, including field studies to complete our analysis to understand the effect of these narratives on actors' strategies. Future studies also need to investigate what compromises can be made between the different types of bioeconomy, and their practical impact on the economy, society, and the environment.

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References

Achilladelis, B., Schwarzkopf, A., Cines, M., 1990. The dynamics of technological innovation: the case of the chemical industry. Res. Policy 19, 1–34. https://doi.org/10.1016/0048-7333(90)90032-2.

Aguilar, A., Bochereau, L., Matthiessen, L., 2009. Biotechnology as the engine for the knowledge-based bio-economy. Biotechnol. Genet. Eng. Rev. 26, 371–388. https://doi.org/10.5661/bger-26-371.

Asada, R., Stern, T., 2018. Competitive bioeconomy? Comparing bio-based and non-bio-based primary sectors of the world. Ecol. Econ. 149, 120–128. https://doi.org/10.1016/j.ecolecon.2018.03.014.

Bais, A.L.S., Lauk, C., Kastner, T., Erb, K., 2015. Global patterns and trends of wood harvest and use between 1990 and 2010. Ecol. Econ. 119, 326–337. https://doi.org/10.1016/j.ecolecon.2015.09.011.

Baka, J., Bailis, R., 2014. Wasteland energy-scapes: a comparative energy flow analysis of India's biofuel and biomass economies. Ecol. Econ. 108, 8–17. https://doi.org/10.1016/j.ecolecon.2014.09.022.

Baranoff, F.I., 1918. 1925. On the Question of the Biological Foundation of Fisheries. On the Question of the Dynamics of the Fishing Industry, Reed. Indiana University, Bloomington, pp. 1945.

Bauer, F., 2018. Narratives of biorefinery innovation for the bioeconomy—conflict, consensus, or confusion? Environ. Innov. Soc. Trans. 28, 96–107. https://doi.org/10.1016/j.eist.2018.01.005.

Beckert, J., 2016. Imagined Futures: Fictional Expectations and Capitalist Dynamics. Harvard University Press, Cambridge, Massachusetts.

Belussi, F., 2016. The implementation of a new game strategy in biotech form from start-up to acquisition: the case of Fidia Advanced Biopolymers (now Anika Therapeutics) of Abano Terme. In: Belussi, F., Orsi, L. (Eds.), Innovation, Alliances, and Networks in High-tech Environments. Routledge, pp. 337–352.

Birch, K., 2017. Innovation, regional development and the life sciences: beyond clusters. In: Regions and Cities, First published ed. Routledge, Taylor & Francis Group, London New York.

Bud, R., 1991. Biotechnology in the twentieth century. Soc. Stud. Sci. 21, 415–457. https://doi.org/10.1177/030631291021003002.

Bugge, M., Hansen, T., Klitkou, A., 2016. What is the bioeconomy? A review of the literature. Sustainability 8, 691. https://doi.org/10.3390/su8070691.

Carlson, R.H., 2010. Biology is Technology: The Promise, Peril, and New Business of Engineering Life. Harvard Univ. Press, Cambridge, Mass.

Cherubini, F., Jungmeier, G., Wellisch, M., Willke, T., Skiadas, I., Van Ree, R., de Jong, E., 2009. Toward a common classification approach for biorefinery systems. Biofuels Bioprod. Biorefin. 3, 534–546. https://doi.org/10.1002/bbb.172.

Clark, C.W., 1976. Mathematical Bioeconomics : the Optimal Management of Renewable Resources. John Wiley, New York.

Costanza, R., Daly, H.E., 1992. Natural capital and sustainable development. Conserv. Biol. 6, 37–46. https://doi.org/10.1046/j.1523-1739.1992.610037.x.

de Jesus, A., Mendonça, S., 2018. Lost in transition? Drivers and barriers in the eco-innovation road to the circular economy. Ecol. Econ. 145, 75–89. https://doi.org/10.1016/j.ecolecon.2017.08.001.

de Jong, E., Higson, A., Walsh, P., Wellisch, M., 2012. Product developments in the bio-based chemicals arena. Biofuels Bioprod. Biorefin. https://doi.org/10.1002/bbb.1360. (n/a-n/a).

Dupuy, J.-P., 2004. Pour un catastrophisme éclairé: quand l'impossible est certain. Éditions du Seuil, París.

Dupuy, R., Roman, P., Mougenot, B., 2015. Analyzing socio-environmental conflicts with a commonsian transactional framework: application to a mining conflict in Peru. J. Econ. Issues 49, 895–921. https://doi.org/10.1080/00213624.2015.1106200.

Espinoza Pérez, A.T., Camargo, M., Narváez Rincón, P.C., Alfaro Marchant, M., 2017. Key challenges and requirements for sustainable and industrialized biorefinery supply chain design and management: a bibliographic analysis. Renew. Sust. Energ. Rev. 69, 350–359. https://doi.org/10.1016/j.rser.2016.11.084.

European Commission, 2005. New Perspectives on the Knowledge-based Bioeconomy.

European Commission, 2012. Innovating for Sustainable Growth: A Bioeconomy for Europe. (Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions No. SWD(2012) 11 final).

European Commission, Directorate-General for Research and Innovation, 2018. A Sustainable Bioeconomy for Europe: Strengthening the Connection Between Economy, Society and the Environment: Updated Bioeconomy Strategy.

Falcone, P., Imbert, E., 2018. Social life cycle approach as a tool for promoting the market uptake of bio-based products from a consumer perspective. Sustainability 10, 1031. https://doi.org/10.3390/su10041031.

Felt, U., 2007. Taking European Knowledge Society Seriously, Report of the Expert Group on Science and Governance to the Science, Economy and Society Directorate, Directorate-General for Research, European Commission. Directorate-General for Research - European Commission, Brussels.

Festel, G., Detzel, C., Maas, R., 2012. Industrial biotechnology - markets and industry structure. J. Commer. Biotechnol. 18, 11–21.

Fevolden, A., Coenen, L., Hansen, T., Klitkou, A., 2017. The role of trials and demonstration projects in the development of a sustainable bioeconomy. Sustainability 9, 419. https://doi.org/10.3390/su9030419.

Finlay, M.R., 2003. Old efforts at new uses: a brief history of chemurgy and the American search for biobased materials. J. Ind. Ecol. 7, 33–46. https://doi.org/10.1162/108819803323059389.

Franceschini, S., Pansera, M., 2015. Beyond unsustainable eco-innovation: the role of narratives in the evolution of the lighting sector. Technol. Forecast. Soc. Chang. 92, 69–83. https://doi.org/10.1016/j.techfore.2014.11.007.

Geels, F.W., 2004. From sectoral systems of innovation to socio-technical systems. Res. Policy 33, 897–920. https://doi.org/10.1016/j.respol.2004.01.015.

Georgescu-Roegen, N., 1975a. Bio-economics aspects of entropy. In: Kubat, L., Zeman, J. (Eds.), Entropy and Information in Science and Philosophy. Elsevier, Amsterdam, pp. 125–142.

Georgescu-Roegen, N., 1975b. Energy and economic myths. South. Econ. J. 41, 347. https://doi.org/10.2307/1056148.

Georgescu-Roegen, N., 1978. De la science économique à la bioéconomie. Rev. Econ. Polit. 88, 337–382.

Georgescu-Roegen, N., 1986a. Man and production. In: Baranzini, M., Scazzieri, R. (Eds.), Foundations of Economics: Structures of Inquiry and Economic Theory. Basil Blackwell, Oxford, pp. 247–280.

Georgescu-Roegen, N., 1986b. The entropy law and the economic process in retrospect. East. Econ. J. 12, 3–25.

Giampietro, M., Mayumi, K., 2009. The Biofuel Delusion: The Fallacy of Large-scale Agro-biofuel Production. Earthscan, London; Sterling, VA.

Giampietro, M., Ramos-Martin, J., 2005. Multi-scale integrated analysis of sustainability: a methodological tool to improve the quality of narratives. Int. J. Glob. Environ. Issues 5, 119–141. https://doi.org/10.1504/IJGENVI.2005.007989.

Gordon, H.S., 1954. The economic theory of a common-property resource: the fishery. J. Polit. Econ. 62, 124–142. https://doi.org/10.1086/257497.

Hajer, M., Versteeg, W., 2005. A decade of discourse analysis of environmental politics: achievements, challenges, perspectives. J. Environ. Policy Plan. 7, 175–184. https://doi.org/10.1080/15239080500339646.

Hansen, A., Budde, J., Karatay, Y., Prochnow, A., 2016. CUDe—carbon utilization degree as an Indicator for sustainable biomass use. Sustainability 8, 1028. https://doi.org/10.3390/su8101028.

Hellsmark, H., Frishammar, J., Söderholm, P., Ylinenpää, H., 2016. The role of pilot and demonstration plants in technology development and innovation policy. Res. Policy 45, 1743–1761. https://doi.org/10.1016/j.respol.2016.05.005.

Jasanoff, S., Kim, S.-H. (Eds.), 2015. Dreamscapes of Modernity: Sociotechnical Imaginaries and the Fabrication of Power. The University of Chicago Press, Chicago; London.

Jullien, B., Smith, A., 2011. Conceptualizing the role of politics in the economy: industries and their institutionalizations. Rev. Int. Polit. Econ. 18, 358–383. https://doi.org/10.1080/09692291003723615.

Kamm, B., Gruber, P.R., Kamm, M. (Eds.), 2010. Biorefineries - Industrial Processes and Products: Status Quo and Future Directions. Wiley-VCH, Weinheim.

Krauss, J.B., Kuttenkeuler, D., 2018. Intellectual property rights derived from academic research and their role in the modern bioeconomy—a guide for scientists. New Biotechnol. 40, 133–139. https://doi.org/10.1016/j.nbt.2017.06.013.

Langeveld, H., Meeusen, M., Sanders, J. (Eds.), 2010. The Biobased Economy: Biofuels, Materials and Chemicals in the Post-oil Era. Earthscan, London; Washington, DC.

Levallois, C., 2010. Can de-growth be considered a policy option? A historical note on Nicholas Georgescu-Roegen and the Club of Rome. Ecol. Econ. 11, 2271–2278.

Levidow, L., Birch, K., Papaioannou, T., 2012. EU agri-innovation policy: two contending visions of the bio-economy. Crit. Policy Stud. 6, 40–65. https://doi.org/10.1080/19460171.2012.659881.

Levidow, L., Birch, K., Papaioannou, T., 2013. Divergent paradigms of European agro-food innovation: the knowledge-based bio-economy (KBBE) as an R&D agenda. Sci. Technol. Hum. Values 38, 94–125. https://doi.org/10.1177/0162243912438143.

Martinez-Alier, J., 1997. Some issues in agrarian and ecological economics, in memory of Georgescu-Roegen. Ecol. Econ. 22, 225–238. https://doi.org/10.1016/S0921-8009(97)00076-1.

Martinez-Alier, J., Pascual, U., Vivien, F.-D., Zaccaï, E., 2010. Sustainable de-growth: mapping the context, criticisms and future prospects of an emergent paradigm. Ecol. Econ. (9), 1741–1886.

McCormick, K., Kautto, N., 2013. The bioeconomy in Europe: an overview. Sustainability 5, 2589–2608. https://doi.org/10.3390/su5062589.

McKelvey, M., 2007. Biotechnology industry. In: Hanusch, H., Pyka, A. (Eds.), Elgar Companion to Neo-Schumpeterian Economics. Edward Elgar Publishing, pp. 607–620.

Meadows, D.H., Meadows, D.L., Randers, J., Behrens III, W.W., 1972. The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind. Universe Books, New York.

Mowery, D., Sampat, B., 2005. The Bayh-Dole Act of 1980 and university–industry technology transfer: a model for other OECD governments? J. Technol. Transfer. 30,

115–127.
Mustar, P., Wright, M., Clarysse, B., 2008. University spin-off firms: lessons from ten years of experience in Europe. Sci. Public Policy 35, 67–80. https://doi.org/10.3152/030234208X282862.
National Research Council of the National Academies, 2015. Industrialization of Biology: A Roadmap to Accelerate the Advanced Manufacturing of Chemicals. National Research Council.
OECD, 1996. The Knowledge-based Economy (No. OCDE/GD(96)102).
OECD, 1998. 21st Century Technologies - Promises and Perils of a Dynamic Future. OECD.
OECD, 2017a. Biomass for a Sustainable Bioeconomy: Technology and Governance (No. DSTI/STP/BNCT(2016)7/FINAL). OECD.
OECD, 2017b. Biorefineries Models and Policy (No. DSTI/STP/BNCT(2016)16/FINAL). OECD.
OECD, 2017c. Towards Bio-production of Materials: Replacing the Oil Barrel (No. DSTI/STP/BNCT(2016)17/FINAL). OECD.
OECD, 2009. The Bioeconomy to 2030 : Designing a Policy Agenda. OECD, Paris.
Patermann, C., Aguilar, A., 2018. The origins of the bioeconomy in the European Union. New Biotechnol. 40, 20–24. https://doi.org/10.1016/j.nbt.2017.04.002.
Philp, J., 2018. The bioeconomy, the challenge of the century for policy makers. New Biotechnol. 40, 11–19. https://doi.org/10.1016/j.nbt.2017.04.004.
Powell, W., Koput, K., Smith-Doerr, L., 1996. Interorganizational collaboration and the locus of innovation : networks of learning in biotechnology. Adm. Sci. Q. 41, 116–145.
Ramcilovic-Suominen, S., Pülzl, H., 2018. Sustainable development – a 'selling point' of the emerging EU bioeconomy policy framework? J. Clean. Prod. 172, 4170–4180. https://doi.org/10.1016/j.jclepro.2016.12.157.
Saltelli, A., Giampietro, M., 2017. What is wrong with evidence based policy, and how can it be improved? Futures 91, 62–71. https://doi.org/10.1016/j.futures.2016.11.012.
SCAR, 2015. Sustainable Agriculture, Forestry and Fisheries in the Bioeconomy - A Challenge for Europe. 4th Foresight Exercise. European Commission - Directorate General for Research and Innovation.
Sokka, L., Koponen, K., Keränen, J.T., 2015. Cascading Use of Wood in Finland - With Comparison to Selected EU Countries (No. VTT-R-03979-15). VTT.
Staffas, L., Gustavsson, M., McCormick, K., 2013. Strategies and policies for the bioeconomy and bio-based economy: an analysis of official national approaches. Sustainability 5, 2751–2769. https://doi.org/10.3390/su5062751.
Tukiainen, S., Granqvist, N., 2016. Temporary organizing and institutional change. Organ. Stud. 37, 1819–1840. https://doi.org/10.1177/0170840616662683.
Vatn, A., 2017. Critical institutional economics. In: Spash, C.L. (Ed.), Routledge Handbook of Ecological Economics - Nature and Society. Routledge, Taylor & Francis Group, pp. 29–38.