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REVIEW PAPER

Environmental and Ecological Aspects in the Overall Assessment of Bioeconomy

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Abstract Bioeconomy solutions potentially reduce the utilization demand of natural resources, and therefore, represent steps towards circular economy, but are not per se equivalent to sustainability. Thus, production may remain to be achieved against losses in natural resources or at other environmental costs, and materials produced by bioeconomy are not necessarily biodegradable. As a consequence, the assumption that emerging bioeconomy by itself provides an environmentally sustainable economy is not justified, as technologies do not necessarily become sustainable merely through their conversion to using renewable resources for their production. A source of the above assumption is that the utility of bioeconomy is mostly assessed in interaction between technology developers and economists, resulting in biased assessment with private commercial technology benefits being included, but environmental costs, especially longer term ones, not being sufficiently considered in the economic models. A possible solution to this conceptual contradiction may come from bioethics, as a strong concept in environmental ethics is that no technological intervention can be imposed on nature beyond its receptive capacity. To achieve a better balanced analysis of bioeconomy, environmental and ecological, as well as non-economic social aspects, need to be included in the overall assessment.

Keywords Bioeconomy · Circular economy · Ecological aspects · Natural resources · Bioethics

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Introduction

There are complex tensions—sometimes contradictions—between two central policy commitments of most modern democratic regimes, namely the emerging bioeconomy and sustainable development. While the latter is endorsed in for example the UN Convention on Biodiversity as well as the EU Lisbon Treaty as a constitutional principle for all relevant legislative Directives, developing the bioeconomy is also a universal driving concern for policy, R&D, and innovation. For reconciling emerging bioeconomy developments with genuine sustainable development however, a more detailed knowledge is needed about what comprises the bioeconomy, what is its contribution to economic growth, including possible negative consequences which may have been (knowingly or inadvertently) externalized. For example, the major current commitment in global agriculture to genetically modified (GM) crops, as a bioeconomic commercial scale innovation from the 1990s, has also built the need for chemical herbicides into its main crop-innovation biotechnologies, and these chemicals are controversial in terms of health and environmental impacts, e.g. the recent case of the herbicide active ingredient glyphosate and its formulating agent polyethoxylated tallowamine (POEA). How all of these factors can be reliably measured is also an important issue for documenting the contribution and for assessing the impacts of supporting policies as well as policies responding to citizens' concerns. An equally important and possibly even more urgent issue is, however, whether currently dominant bioeconomy solutions do indeed represent a step towards the ultimate sustainable development goal of a circular economy, i.e. ecological "zero waste" technology (Stahel 2016), or towards truly sustainable ecocycles (Nemethy and Komives 2016). From the disciplinary perspectives of economic analysis and policy driven strategies, the market potential, profitability and some (though selective) societal aspects of bioeconomy have been analyzed. Much less concern has been shown, and even less implemented, to reveal environmental and ecological costs, and therefore, in spite of the achievements realized so far, bioeconomy still operates on the basis of natural resource utilization, conversion of natural assets into more "useful" forms (i.e. economically measurable, but neglecting the costs of natural resources-depletion), while creating less "useful" by-products. For a real transition a true conversion to the principles of ecological economics (Costanza et al. 1997, 2015; Daly and Farley 2011; Baveye et al. 2013), reliance on biomimicry to support ecological innovations instead of exploitative technological approaches (Blok and Gremmen 2016), and the abandonment of the economic growth concept (El-Chichakli et al. 2016) is needed. Without a conceptually improved, ecology-based assessment and implementation, bioeconomy will remain a substantially improved, yet fundamentally equivalent version to unsustainable resource-intensive chemical technologies. 'Bio-'as a preface does not automatically mean ecologically sound, and without the transformations indicated above, and discussed further below, public policy and debate could mislead itself into "talking the talk, but not walking the walk", of sustainability.

Bioeconomy as a Concept

The Millennium Ecosystem Assessment (UNEP-WRI 2005) by the United Nations Environment Programme evidenced the effects of anthropogenic activities on the ecosystems and services they provide, such as food, water, disease management, climate regulation, spiritual fulfilment and aesthetic enjoyment. It also further emphasized the value of research at the interfaces between natural and social sciences, and humanities (Reid and Mooney 2016); and it urged efforts to conserve these more complex to measure thus too-often neglected economic assets in order to achieve sustainability. In an attempt towards such a sustainable management practice, bioeconomy (EC 2012a) (formerly bio-based economy—Langeveld et al. 2010) aims for the production and utilization of renewable biological resources in agribusiness. Bio-based products have been specified as one of the six areas selected for the Lead Market Initiative for the EU (EC 2008). The European Union defines bioeconomy as "the production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy" (EC 2012a, b), often produced in systemic, both materially and financially interconnected networks on the basis of the cascade principle (de Besi and McCormick 2015). Bioeconomy is being implied in various segments of the industrial and agribusiness sectors, including agriculture, forestry, fisheries, food, pulp and paper production, parts of chemical, biotechnological and energy industries. These areas do not develop as insular entities, but influence each other, demanding an integrated systems approach in their regulation, currently occasionally fragmented into risk assessment or management in artificially isolated components.

The main objectives of growth of the bioeconomy in Europe are: (a) ensuring food security; (b) managing limited and depleting natural resources sustainably; (c) reducing dependence on non-renewable resources; (d) mitigating and adapting to climate change; as well as (e) creating jobs and maintaining European competitiveness (EC 2012b). The opportunities (or hopes) regarding bioeconomy include its potential to move production technologies towards a renewable resource base; to reduce pollution; to improve and enhance food security; and to accelerate adaptation and mitigation of climate change. These hopes are aimed to be achieved by broadening novel science-based applications, yet scientific literature surveys indicate that the concept of bioeconomy is conceived rather differently from various stakeholder perspectives. The industrial biotechnology vision focuses on the rapid utilization and commercialization of biotechnology research in various sectors of the economy; the bio-resource vision emphasizes sustainable utilization of biological raw materials; while the more recent, and yet less prominent, bio-ecology vision promotes maintenance or improvement of biodiversity and ecosystem services, as well as the avoidance of monocultures and soil degradation (Bugge et al. 2016). Due to the complexity of the issues, the topic has been evaluated in detail by the Standing Committee of Agricultural Research (SCAR) of the European Commission (EC 2011, 2015). Thus, the forecasted broadening of technology development is faced with serious challenges from at least three main directions, such as knowledge-based technology itself, the prevailing natural resources base, and the policy environment. All of these are also influenced, including in terms of continuing concentration of ownership over such as intellectual property rights (IPRs), by political economy. To enhance a properly open and more diverse knowledge base for sustainability (Leach et al. 2010), effectively targeted research, development and innovation (RDI) need to be promoted; access to knowledge has to be enhanced; skilled workforces need to be developed; and environmental ethics need to be taken into more pronounced consideration to discriminate between technology being integrated in or being imposed on nature. In this context, targeted RDI means focusing on true sustainability instead of global business interests, monopoly control, IPRs or distribution (see later, under 'The policy environment'). In spite of all potential achievements in technology, however, natural resources remain the key limiting factor, as long as their utilization rate exceeds their natural renewal rate. It may be unsustainable therefore, if a new crop is innovated which may produce more yield but only on condition that more energy, chemicals and other resources are used, and which reduces both agricultural and natural biodiversity. Therefore, it should be the main role of a safe and efficient regulatory—and innovation—system that it is formulated so as to harmonize the production goals with the real background resource capacity.

Bioeconomy and Economic Growth

By producing biofuels and bio-based chemicals on the basis of renewable biological resources, bioeconomy currently has substantial economic growth potential. However, this growth is limited by two main factors. The initial expansion of the sector will eventually need to lessen as bioeconomy solutions gradually replace fossil fuels-based chemical technologies. As bioeconomy reaches full capacity, the external limiting factor is the renewal rate of the bio-resources used. Should bioeconomy go beyond that limit, it would fail to achieve an equilibrium state, and would fall into the unsustainability trap of fossil fuels-based chemical technologies. The renewal rate should not be underestimated, as it allows substantial steady-state operational capacity, but obviously it cannot be considered limitless, either.

Bioeconomy and Circular Economy

From an ecological aspect, a circular economy in its objective to produce no waste or pollution is a concept to organize industrial economy on the basis of stable ecosystems, where the output of every technological process serves as an input for another process or processes. Thus, the concept is a 21st century manifestation of the pioneering approaches in the early seventies of the last century by Barry Commoner (Commoner 1971) and the Club of Rome (Meadows et al. 1972). Ecological innovation, including biomimicry, can provide solutions that are better embedded and more in harmony with natural ecosystems (Blok and Gremmen 2016), and thus provide steps towards a circular economy. Bioeconomy in its particular form of technological solutions represents a step towards the principle of a circular economy; but it is not equivalent with it. Bioeconomy does not accomplish circular economy, but aims "to pave the way to a more innovative, resource efficient and competitive society that reconciles food security with the sustainable use of renewable resources for industrial purposes, while ensuring environmental protection" (EC 2012a). The ambiguous idea of a "competitive society" in this statement would also need some collective reflection. Is this "competitive" in the sense which dominates and drives current, unsustainable, policy and society? Or might it mean a form of society which is more "competitive with" and more humanly civilized and attractive than conventional unsustainable societal habits and "consumption-as-therapy" drivers of demand for commodities which extend—and shape—production systems far beyond what would realistically be called meeting social *needs*? This is part of the general point that sustainability-governance would need not only to manage *supply* of goods and services within any economy we manage. It would also have to manage *demand* to reasonable and sustainable levels, as has been extensively analyzed and debated (Wynne 2011; Owen et al. 2013) for example for energy and food.

Cascading use of Biomass

Besides the use and regeneration of renewable resources, a key concept in bioeconomy to achieve resource efficiency is the so-called cascade principle. The bio-resource aspect of bioeconomy emphasizes cascading use of biomass and raw bio-materials in recycling, to maximize the efficiency of biomass use. Yet the various and often long-term, indirect environmental and economic impacts of increased industrial biomass-uses need to be better understood (Keegan et al. 2013; Bugge et al. 2016).

The cascade principle is mentioned in particular cases, referring to innovation cascades, i.e. series of innovative technologies built on each-other. The two types of cascades—cascades of material utilization and of technology development—are mutually related. The development of cascading processing of new materials requires novel technologies, and vice versa, these emerging technologies may produce new by-products needed to be cycled into the processing cascade. Moreover, as the number of technologies increases, the possibilities for their recombination also rises (Arthur 2009), making innovation cascades possible.

Knowledge-Based Technology

Bioeconomy approaches aim to replace the functions of conventional synthetic, usually fossil fuels-based industrial chemicals by new technologies based on biological processes, natural or GM organisms, fermentation, biotechnology and molecular biology. This has led to a rapid expansion of the bioeconomy market, realizing an annual turnover reported by Eurostat to be 2,1 trillion EUR for the EU (EU-28) in 2013 (Piotrowski et al. 2016). With food, beverages and tobacco products excluded from this, the remaining bio-based sector represents an annual turnover of 1 trillion EUR, biofuels and bioenergy accounting for 8%, agriculture and forestry for 43%.

Within bioeconomy, particular emphasis has been given to GM crops, which has generated a politically heated international debate. Scientific opinions claiming the safety of current (first generation) agricultural biotechnology (GM) products and urging their application (Barrows et al. 2014; Domingo 2016) confront others claiming lack of evidence on their safety (Hilbeck et al. 2015; Krimsky 2015), and exaggeration of what risk assessment can demonstrate as so-called “lack of harm”. Both positions were considered in the latest evaluation by the US National Academy of Sciences (US NAS 2016). GM crops developed by agricultural biotechnology are classified into several (four) generations on the basis of the type of genetic transformation applied and intended utilization. Following its mandate (EC 2002), the European Food Safety Authority (EFSA) is assigned to carry out environmental and food safety risk assessment of these GM crops if used for food and feed purposes. First generation GM crops are modified for their agronomic traits, their main representatives containing transgenic traits that result in resistance to insect pests or tolerance to particular herbicides. These GM crops rely on pesticide applications: the crop either produces an insecticide, or it is designed for actual herbicides (e.g. glyphosate along with its formulnt POEA) being sprayed on it. Second generation GM crops contain genetic transformations intended to improve/modify their product quality (composition, tolerance to environmental conditions like drought, etc.), while third generation GM crops are intended to express industrial products and pharmaceutical drugs. Somewhat distant from the first three, fourth generation GM crops are being produced with new methods in molecular biology, also termed emerging technologies (Lusser et al. 2011). Although these emerging technologies alter plant genomes so as to create new plant varieties, it is debated whether all result in GM organisms according to the legal definition set in the EU (EC 2001). Industrial and pro-GM scientific bodies are promoting deregulation of such new technologies or their products on the claim that they are not GM. This has extended and elaborated on the long-standing vigorous societal and scientific debates at the UN Convention on Biodiversity and in Europe, regarding the environmental safety and regulatory questions surrounding all four generations of GM crops. In this context, it has been stated that the EU, unlike the US, is less biotech oriented, or even negative about biotechnology. A correction to this opinion is that the EU is not less biotech oriented, but less oriented to open biotechnologies (see below)—closed system biotechnologies (e.g. the pharmaceutical industry’s use of GM in insulin production) are not subject to greater limitation in the EU than in the US.

In spite of the spectacular boom in the bioeconomy sector, several controversies remain unresolved, considering technology, societal and assessment-related issues. Besides resource utilization, a major issue regarding the environmental aspect of bioeconomy technologies is the question mentioned above and discussed in detail in the next section. This question is whether the technology is isolated from the environment, or open to it. In fact, this aspect is not unique to bioeconomy technologies, but has to be considered for all technologies—should technologies be fully open to the environment, as in agriculture, fisheries or forestry; isolated by physical means and waste management methods, such as chemical industry technologies; or fully isolated, such as technologies used in isotope techniques.

A means to overcome these conflicts and consequent public distrust has been proposed through the approach of responsible research and innovation (RRI) (Asveld et al. 2015). If implemented universally RRI should provide transparency and responsiveness, and is also aimed to enhance public trustworthiness in socially sensitive issues involving bioeconomy and other technologies.

Another burning issue relates to the accelerating rate of innovation occurring. It is often questionable, whether health and environmental risk assessment is able to keep pace with, or rather to resist, the powerful demand for rapid commercial development seen e.g. for GM organisms [GMOs, also termed living modified organisms, LMOs in the UN Cartagena Biosafety Protocol (CBD 2000)], by the Precautionary Principle declared by the implemented in over 160 signatory countries and assessed in and compared among nine of them, Australia, Brazil, Canada, China, Cuba, Germany, Japan, South Africa and the USA (Flint et al. 2012).

Natural Resources

Socio-economic and Earth System trends between 1750 and 2010 on the basis of analyses of resource utilization evidence that anthropogenic activities have resulted in more extensive transformations in our environment during the last half-century than at any period in the Earth's known history (UNEP-WRI 2005; Steffen et al. 2015). Data indicate that while population growth has been seen in the non-OECD world since 1950, the vast majority of the world's economy (measured in gross domestic product, GDP) and consumption is realized by OECD countries. Economic growth has been achieved against growing costs in natural resources and ecosystem services, and has caused the largest human imprint on the planet, the Anthropocene Era (Crutzen 2002). This rate of reduction in fossil raw materials and ecosystem services cannot subsist as planetary boundaries are claimed to have been reached, or perhaps exceeded, with the greatest emphasis on the extreme rate of global biodiversity loss. Yet, environmental issues related to bioeconomy are mentioned mostly from a human population aspect, with the strongest focus on climate change, much less from the aspect of the state and adequacy of natural resources. Moreover, the decreasing availability of natural resources is even mentioned as a factor in favour of bioeconomy (bio-based vs. fossil products).

The Earth System aspects of bioeconomy have to be assessed by both environmental and ecological perspectives. Thus, environmental (pollution, resource utilization) and ecological (biodiversity) aspects should both be an integral part of the assessment of bioeconomy innovations aiming to achieve a circular economy.

Environmental aspects cover the use of natural resources, including the balance (use minus renewal) of given resources, such as plants, minerals, nutrients or fossil fuel, and also evaluation of alternative uses of arable land (land used for cultivation of food/feed or energy crops). Ecological aspects cover biodiversity of the utilized areas as habitats, maintaining ecosystem services (UNEP-WRI 2005) (supporting or habitat, provisioning, regulating and cultural services) provided by various participants of the given ecosystems. Careful assessment of the changes in the natural resources and biodiversity of the ecosystem due to different technologies should be an integral part of bioeconomy assessment, and therefore, environmental science experts and ecologists should be included in such analysis.

Environmental pollution remains high in various regions of the world, justifying the need for programs to re-establish natural ecosystems, to reduce water and air pollution, to serve soil protection, and to protect animal/plant species and their habitats. This applies to the Pannonian Biogeographical Region (see below) of the EU, where indices indicate deterioration (Kelemen et al. 2014), including river natural floodplain ecosystems (e.g. the Danube) which need to be restored.

Major environmental constraints to technologies (including bioeconomy) are the availability/exploitation of non-renewable natural resources (e.g. fossil fuels, phosphate, nitrogen and carbon dioxide); the limited capacity/renewal rate of renewable natural resources; as well as the availability of water (fresh water and seas/oceans) and land (crop- and shrub-lands, pastures, forests, even urban areas). Soil is also a natural resource. Although soil fertility is renewable by character (its renewability is the basis or our existence), its renewal capacity is limited: intensive cultivation, either for food of for bioeconomy purposes, causes chemical pressure on soil ecosystems and removes energy represented by soil nutrients and components. Intensive soil utilization leaves less energy resources to maintain soil ecosystem functions, which jeopardizes soil fertility. Such degradation of ecosystem functions due to unsustainable industrial agricultural production needs to be avoided, not only from an ecological, but even from a pragmatic, productivity-oriented aspect, as compromized ecosystem functions eventually can maintain neither habitat ecosystem services, nor agricultural production, as the latter is also tightly interlinked with natural systems (Miko and Storch 2015).

As stated in the EU Nature Directives i.e. the Habitats Directive (EEC 1992) and the Birds Directive (EC 2009a), Member States of the EU are legally bound to preserve their natural ecosystems in their existing state. To support compliance with this requirement, the EU is divided into nine terrestrial and five marine biogeographical regions by their ecological conditions in the Natura 2000 network (ten Brink et al. 2011). Of the nine terrestrial regions, the Pannonian Biogeographical Region is one with outstandingly high biodiversity (EC 2009c), but over 50% of its habitats are assessed as ‘unfavourable—bad’, exceeding the average of the other biogeographical regions (EEA 2010).

An essential environmental issue regarding bioeconomy technologies, is not actually related to features specific to bioeconomy, but is derived from the isolation characteristics of these (and other) technologies. Areas of applied biotechnology are often described with colours: white, red, blue and green biotechnology referring to industrial, health, marine and agricultural applications. Of these, white biotechnology solutions are typically closed systems, operated in closed reactors and subject to strict waste and pollution management. In contrast, blue and particularly green biotechnologies are typically open to the environment throughout their entire process, although also implying waste management practices. This is of particular importance in the application of living organisms, both in cases of invasive alien species to given regions and of GM organisms, since these can reproduce of their own accord once released. The highest concern relates to microorganisms, where similar isolation criteria as those set for closed systems should apply, depending on the type and potential severity of effects of the microorganisms. In the EU these are set by legal measures (EEC 1989), updated several times later (EC 2000).

Biofuels

Increasing utilization of renewable energy resources instead of fossil fuels is certainly an advantage, a step towards a circular economy. Thus, the use of renewable resources for energy production is promoted in the EU by policy (EC 2009b) and by biofuel certification to favour environmental and social sustainability standards (Pols 2015). In fact, not a single, but several steps, as biofuel technologies have been developed by now in several generations on the basis of the biological material the technology is based on (Aro 2016). (Coincidentally biofuel technologies are also classified into four generations, like GM crops, but the two classifications do not relate to each other.) First generation biofuels are produced from sugar, lipid or starch extracted from food crops (EASAC 2012). Thus, first generation biofuels pose sustainability challenges and represent a direct competition between food and bioenergy use of crops and land (Naik et al. 2010; Mohr and Raman 2013; Rulli et al. 2016), and pose the same environmental risks associated with intensive agriculture: biodiversity threats from the use of crop monocultures, environmental contamination from pesticide use, water use for irrigation, soil acidification and erosion, increased carbon emissions from ploughing, indirect fossil fuel use and nitrogen oxide emissions from industrial fertilizers. To avoid this controversy, later generations of biofuels, termed advanced biofuels have also been developed (EASAC 2012). Second generation biofuels are based on cellulose, hemicellulose, lignin or pectin from non-food plant materials, wood, organic waste, food crop waste or specific biomass crops (Sims et al. 2010); third generation biofuel technologies are based on biomass from algae or other aquatic autotrophic organisms (Alaswad et al. 2015); while fourth generation technologies combine biofuel production with CO_2-capture and storage (CCS) in deep geological formations, e.g. old oil and gas fields or saline aquifers.

Practical utility of advanced biofuels is seen in the production of cellulosic chemicals (bioethanol), biokerosene, green diesel, bio-based marine diesel and other biofuels. With the achievements of emerging bioeconomy, the proportion of such biofuels is increasing, and industrially developed countries commit themselves to cover a certain proportion of their energy needs with biofuels. However, the production of these biofuels has to be managed in a sustainable way to fulfil these commitments. The assessment of the environmental and socioeconomic impacts of biofuels in a more coherent and policy-relevant manner has been urged (Lovett et al. 2011; Gasparatos et al. 2013), including environmental sustainability indicators (McBride et al. 2011). Advanced biofuel technologies have been advocated for reducing the social and environmental risks associated with biofuel production and usage (UNCTAD 2014). Yet such ‘advanced’ biotechnologies also have their environmental risks, e.g. those related to ecological consequences of cultivation or biomass processing; environmental release of GM plants (should GM energy crops be utilized); or CO_2-leakage in CCS, ocean acidification and its consequences on ecosystem functions (Phelps et al. 2015; Wang et al. 2016). Moreover, the biofuel sector is subject to a current market paradox, as explained below: expansion in biofuel utilization increases overall fuel supplies, which in turn, results in price reductions of fossil fuels as well.

Bio-based Products

Bio-based technologies do not produce solely biofuels, but give rise to numerous bio-based chemicals, often difficult to produce by the conventional chemical industry. These bio-based compounds are often produced in cascades, employing chemical conversion, e.g. solvent or supercritical water extraction, hydrolysis of the biomass, resulting in valuable bio-based substances from technological batches from biofuel or food production technologies (Naik et al. 2010; Nattrass et al. 2016; Snyder 2016). This is supported by the European Bioeconomy Panel and the SCAR Strategic Working Group of the European Commission (EC 2014), and is best exemplified by the cascade use of biomass in the wood industry (Scarlat et al. 2015; Hagemann et al. 2016).

Chemicals/plastics and pharmaceuticals so far represent only 10% of the annual turnover of the bio-based sector (Piotrowski et al. 2016), yet this may be considered the most promising segment within the sector, as bio-based chemicals are being produced in closed system technologies, representing the lowest hazard to the environment.

Bio-based chemicals include biomaterials (such as natural fibres, cellulose, starch, sugars, as well as synthesis gases and oils, e.g. plant and animal oils), of which further derived products (such as glycerol or CO_2), as well as fuels (such as hydrogen, methane or ethanol) are produced. From these intermediates, various organic building blocks (such as alkanes and alkenes, furans and ketones, organic acids and alcohols) are (bio)synthesized and converted into a wide range of chemical products. Leading examples in the bio-based industry include essential amino acids (methionine, lysine) as chemical intermediary compounds and feed additives; organic acids, such as lactic acid for bio-based polymer polylactic acid (PLA) used in 3D printing; succinic acid as raw material for various bioplastics, plasticizers and biosolvents; lauric acid from biooils, and levulinic acid from sugar production; castor oil and related bio-based polyamides; 1,4-butanediol/butandiene and other biomonomers, biopolymers, biorubbers, resins, plasticizers, solvents (ethyl acetate, dimethyl succinate, etc.) and biosurfactants; new fibres from cellulosic chemicals, as well as lignin and bran. Yet, the example with the highest public recognition is probably that of polyethylene furanoate (PEF) bottles, built by the plant carbohydrate-based, so-called YXY-technology, capable of building C_6-sugars from plants through catalytic dehydration, catalytic oxidation followed be catalytic polymerization into 100% bio-based PEF, leading to PlantBottle^{TM} plastic, intended to reach the market by 2020 and replace the current polyethylene terephthalate (PET) bottles. New substances built from raw materials of plant origin by innovative technologies may be advantageous by using renewable resources instead of fossil assets, yet their end product, PEF is not biodegradable, similarly to

PET. Thus the approach is reducing resource-intensity, but it cannot realize a circular economy and therefore, true sustainability, with respect to its waste utilization or recycling.

The Policy Environment

To assess the potential of the emerging bioeconomy, the Organisation for Economic Co-operation and Development compiled a broad-based analysis of the future development perspectives in three sectors where biotechnology has the greatest potential impact: agriculture, health and industry (OECD 2009). Although the bioeconomy/circular economy concept is based on environmental-ecological dimensions; the main driving forces required to underpin its policy and strategy effectiveness are societal/economic, including trade, finance, political economy of RDI, and knowledge transfer between RDI and industry (de Besi and McCormick 2015). Currently, and on a long-term basis, whatever its ecological claims or aspirations, bioeconomy is mostly assessed in interaction between technology developers and economists. This results in biased assessment misnamed as scientific risk assessment for policy, where commercial technology benefits are included, but environmental and social costs not sufficiently considered in the economic and scientific models used.

A societal concern regarding investment and innovation structures is that through current RDI financing, which increasingly prioritizes industrial applications, society is becoming an investor in technology development. This, on the one hand, may be considered contradictory, as the role of the society should be the assurance of public interests, not of business prospects; yet on the other hand, it holds a certain advantage potential, as society may have a better position in assuring issues of sustainability over usual business interests, e.g. IPRs, monopoly or distribution control. As for IPRs, patenting no longer suits bioeconomy, just as other scientific fields with dynamic and interactive complexity, e.g. systems biology or synthetic biology (Cavert 2008). In turn, democratisation of science is becoming of increasing importance (Jasanoff 2006, 2011; Jasanoff et al. 2015), increasing the role of assessment science as impure science in which facts are intermingled with values and judgments (Jasanoff 2015). Whether society as a business investor in bioeconomy protects or advances public welfare depends upon two broad questions. One concerns “protection”, and whether risks of harm to health or the environment are properly researched and controlled; the other concerns, whether the directions of innovation which result from such large public investments, such as the EU’s Horizon 2020 programme 75 billion EURO funding over 7 years, reflect genuine public priorities and concerns, or private commercial competitive ones. On neither of these broad questions can confidence be justified in Europe (Felt and Wynne 2007). Nor in such controversial domains with enormous commercial interests bearing down on regulatory science, can illegitimate conflicts of interest be assumed to be absent (Guillemaud et al. 2016).

The need of a physical land use balance is expressed in terms of technological changes in cropland use and yields achieved (Kuemmerle et al. 2013; Engström et al. 2016) and as limits of bioenergy production (Scarlat et al. 2015). A global land use assessment by UNEP indicated a need for reduction in land use intensity in the EU, so as to reach a global land use target based on the safe operating space (UNEP 2014). In fact, sustainable landscape management has been assumed to be a proper base for sustainable regional development strategies, as natural resources management, biodiversity, environmental protection, ecosystem services, socio-economic sustainability and cultural heritage are considered as its inherent elements (Nemethy and Komives 2016). Yet, the competition between food and non-food applications in bioeconomy for arable land from an ecological aspect is insufficiently recognized (O'Brien et al. 2015), even though land-availability and soil-quality, as well as water-scarcity, are being emphasized as limiting factors.

Bioeconomy modelling and regulatory policies emphasize the environmental issue mostly as a societal need, but in practice they focus rather on business, economy, R&D and consumer issues (food price, choice, and safety), and bioeconomy is mostly presented from the aspect of development and business opportunities in the food and feed, biomaterials and bioenergy (biomass) sectors. Attempts to overcome this deficiency are still coming from economic analyses, with all their recognized inadequacies. Computable general equilibrium (CGE) models have been proposed to analyse the consequences of bioeconomy policies (Francois et al. 2005; van Vuuren et al. 2016), yet dynamic CGE models mostly remain focused only on economic effects in global production and trade, with intermediate linkages between sectors; to scale economies and imperfect competition; and to assess trade impacts on capital stocks through investment effects. All of this ignores the environmental, ecological and social factors (Laurenti et al. 2016) discussed before, and is thus wholly unable to provide a realistic basis for sustainable innovation.

Traditional economic tools may fail to assess the efficacy of bioeconomy: evaluating the bioeconomy sector by measuring its share in the GDP does not give any useful knowledge, can even be harmful, e.g. leading to the market aspect paradox that the use of bio-based products as market competitors of fossil products leads to a decrease in fossil prices, which in turn, stimulates fossil demand and acts against the desired reduction in fossil usage. This trend, although not to a major scale, is documented in the oil sector: by reducing oil prices in oil-importing countries, the introduction of biofuels contributed to a current increase in fossil fuel consumption (Hochman et al. 2010). Official regulatory limitations on fossil fuel consumption may not be unambiguously beneficial either due to their anticipated stimulatory effect on biofuel consumption to secure GDP, that, if unregulated, would increase the demand for land and water resource utilization (Pols 2015). In lieu of GDP as an economic measure, the concept of consumer surplus has been proposed (Zilberman et al. 2013). This, by itself is still a purely economic approach, but a nonstandard definition of consumer surplus in environmental economy allows possible inclusion of the economic evaluation of ecosystem services (Banzhaf and Boyd 2012).

As long as bioeconomy practices, just as other technologies, are evaluated on the basis of the economic growth they allow, their promise to achieve circular economy cannot be accomplished. To achieve a better balanced analysis of bioeconomy, environmental and ecological—and indeed non-economic social—aspects need to be included in the overall assessment.

Conclusion

In spite of the initial ecological approach, altogether, the current business model of the emerging bioeconomy does not appear to be fundamentally different from that of traditional chemical industry, and in reality it focuses on business potential, economic growth and profitability. Therefore, it cannot meet sustainability needs, claims, or aspirations. It can only mitigate unsustainable resource utilization, but does not (yet) hold a promise for a true circular economy. Circular economy cannot be achieved until all products and by-products of technologies gain utility in some other bioeconomy technologies; in other words, no waste is being produced in these processes. Unless they do achieve this, they should not be approved in regulatory processes, but refused until better innovations are developed. Until then, human activity will remain operating on the basis of converting natural resources from their more "useful" forms into their less "useful" forms (Commoner 1971). It is of utmost environmental ethical importance and in turn, practical significance that the ongoing second, bio-based (also termed biomimetic) industrial revolution (Blok and Gremmen 2016) should be transformed from its present inability to enframe its inventions within the copious but demanding limits and processes of natural ecosystems.

In summary, the full and transparent, long-term environmental and ecological assessment of bioeconomy initiatives is urged, in a global context, in all identified biogeographical regions worldwide, and within the EU. This is necessary to ensure their true sustainability, and to press towards development of a circular economy. Assessment should include the environmental status of organic microcontaminants in environmental matrices (including surface water and soil), as well as effects on protected species and habitats, and through them on biodiversity and ecosystem services.

Public Interest Statement

Bioeconomy, as an emerging sector in the national economies of industrial and developing countries, is advocated as a way towards circular economy by the production and utilization of renewable biological resources in agribusiness, bio-based products and bioenergy. Yet in spite of the bio-based approach, bioeconomy solutions cannot provide true sustainability, if they use renewable resources beyond their renewal rate, if they produce non-biodegradable products or wastes resulting in environmental pollution, or if they pose threat to biodiversity. Therefore, as discussed in the present paper, the assessment of bioeconomy innovations on the basis of their current profitability and economic growth is inadequate and misleading, and must consider environmental and ecological aspects rigorously and comprehensively, and not only in appearance.

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Compliance with Ethical Standards

Ethical Standard The Author declares to have received no funding that might cause a conflict of interest with regard to this research.

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