Land Use Policy 66 (2017) 162–171

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Toward a systemic monitoring of the European bioeconomy: Gaps, needs and the integration of sustainability indicators and targets for global land use

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ARTICLE INFO

Keywords:
Land use change
Modeling
Sustainable consumption and production
Footprints
Sustainable development goals
Dashboard

ABSTRACT

The contribution of the EU bioeconomy to sustainable development depends on how it is implemented. A high innovation potential is accompanied by considerable risks, in particular regarding the exacerbation of global land use conflicts. This article argues that a systemic monitoring system capable of connecting human-environment interactions and multiple scales of analysis in a dynamic way is needed to ensure that the EU bioeconomy transition meets overarching goals, like the Sustainable Development Goals. The monitoring should be centered around a dashboard of key indicators and targets covering environmental, economic, and social aspects of the bioeconomy. With a focus on the land dimension, this article examines the strengths and weakness of different economic, environmental and integrated models and methods for monitoring and forecasting the development of the EU bioeconomy. The state of research on key indicators and targets, as well as research needs to integrate these aspects into existing modeling approaches, are assessed. The article concludes with key criteria for a systemic bioeconomy monitoring system.

1. Introduction

The bioeconomy is gaining growing attention as a possible win–win strategy for low-carbon growth and competitiveness in the EU. Leaning on the European Commission's "Bioeconomy Strategy", bioeconomy is defined as "the production [and consumption] of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy" (EC, 2012). It is seen as an opportunity to boost innovation, create jobs in rural and industrial areas, reduce fossil fuel dependence and improve economic and environmental sustainability (EC, 2012).

At the same time, research points to increasing risks associated with a growing bioeconomy, in particular regarding the scale of global land use. Land competition is very likely to increase in the future (UNEP, 2014), both to meet the dietary requirements of a growing world population and to meet energy and material demands in, increasingly, high tech industries and markets for bio-based products. The EU already cannot meet its total demand for food, feed and crop-based products on its own territory (O'Brien et al., 2015a), and it is expected to also become import-dependent for timber and timber-based products in the near future (UNECE et al., 2012). The land footprints, which encompass the amount of global land used to produce goods and services devoted to satisfying the domestic final biomass demand of a country (Arto et al., 2012; Weinzettel et al., 2013), are disproportionately high in the EU. On a per person basis the EU uses around 30% more global cropland than the world average (O'Brien et al., 2015a).

This raises the questions:

- How much land is available to supply the European bioeconomy under conditions of sustainability?
- How much biomass can be sustainably produced per hectare on that land?
- How much and in which way could biomass be used and consumed in the bioeconomy to not exceed the limits of sustainable supply?

To that end, better metrics for monitoring the development of the bioeconomy and benchmarks for judging sustainability are required. This article argues that a framework for systemic monitoring is needed that accounts for the bioeconomy as a whole, takes multiple levels of analysis into account in a dynamic way, and includes indicators and targets for evaluating sustainability. It then assesses the scientific tools that can serve as building blocks for such a framework, focusing in particular on system modeling, and discusses the strengths and weak-

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http://dx.doi.org/10.1016/j.landusepol.2017.04.047
Received 20 December 2016; Received in revised form 14 April 2017; Accepted 29 April 2017
Available online 10 May 2017
0264-8377/

ness of different types of models and methods. Finally, research gaps and needs are identified, in particular toward an integration of indicators and targets in a strategic monitoring dashboard. Although the focus of this article is on land resources, it also addresses approaches to better monitor and model economic potentials, social impacts and other environmental pressures.

2. The need for a systemic monitoring

There is a current fragmentation of research on the bioeconomy. Extensive work has been done to monitor, model and evaluate the impacts and future pathways of specific sectors of the bioeconomy, such as primary sectors (agriculture, forestry) (e.g. Lambin and Meyfroidt, 2011), industrial sectors (food processing, paper, and chemicals) and the energy sector (e.g. Dornburg et al., 2010, Humpenöder et al., 2013). However, analysis covering a comprehensive and overarching bioeconomy perspective, considering e.g. the impacts of structural change in energy sectors on material sectors, and vice versa, is just emerging (Sheppard et al., 2011).

One of the key challenges is linking changes in production and consumption processes related to the bioeconomy to their impacts on the environment both domestically and abroad. This is exemplified by the DPSIR concept[1] (EEA, 1999). Fig. 1 depicts this concept applied to the bioeconomy. It takes into account the underlying drivers of environmental pressures and impacts related to the scale of demand. For example, production and consumption patterns within the economy drive pressures on the environment. These pressures manifest at both local and global scales, but increasingly a geographical gap is seen between the places of production and the places of consumption (Weinzettel et al., 2013; Yu et al., 2013). This means that pressures, such as land use change associated with increasing demands for bio-based products, are not immediately recognized by the manufacturer and the consumer in their immediate environment. Pressures shift the state of the environment and impact the operating systems of the Earth—e.g. land use intensification through mineral fertilizer influences the Earth's biogeochemical cycles for Nitrogen and Phosphorus, greenhouse gas (GHG) emissions affect global circulation systems like the climate and oceans, and land use change affects ecosystem services (Steffen et al., 2015). The impacts of environmental degradation may be classified as environmental (e.g. biodiversity loss), economic (e.g. remediation costs) or social (e.g. migration). While policy responses work to tackle different aspects of the drivers-pressures-state chain, a harmonized approach covering all stages is needed. For instance, focusing on just nature conservation and/or regulations for sustainable production misses the importance of human consumption patterns as an underlining driver of environmental pressures.

Due to the complexity and high level of integration of bioeconomy this type of DPSIR thinking up to now has been applied to certain sectors and areas, but rarely to the bioeconomy as a whole (Bringezu et al., 2009). For example, the direct and indirect land use changes associated with biofuels have received much attention (Lapola et al., 2010). However, biofuels are only one aspect of the bioeconomy leading to land use change. It is the total demand for land-based resources, both crops and timber, which drive changes to the natural environment.

For this reason, a systemic monitoring is needed that is capable of providing an overarching perspective of total bioeconomy impacts both on national and global scales. In order to address problems and e.g. reduce consumption that is excessive in terms of the associated life-cycle-wide pressures, it must also be possible to identify "hot spots" in light of the overarching system. Relevant questions are, for example: What products contribute heavily to the EU's land footprint, and what crops are associated with acute environmental impacts? This implies that a systemic monitoring must cover multiple scales of analysis in a comprehensive way. It would reveal, for example, the high land use intensity of consuming large amounts of meat, considering also feed requirements (Wirsenius et al., 2010; Stehfest et al., 2009), highlighting the need for policies to address and provide the necessary framework conditions for encouraging a shift in dietary habits and reducing food waste (UNEP, 2014).

As impacts of the bioeconomy may first manifest in the future another relevant question of a monitoring framework is: Is the bioeconomy on track to meeting society's overarching goals (e.g. Europe 2020, the Sustainable Development Goals, etc.)? This future perspective requires a better understanding of the amount of biomass available for supplying demand (now and in the future), the EU's expected level of import dependency, as well as potential rebounds related to consumption behaviors. In order to fulfill these needs dynamic modeling tools across space and time are a critical component of a systemic monitoring framework.

In this sense, evaluating the potential impacts of innovation is a challenge. A dynamic, systemic monitoring must take into account, as much as possible, the potential of innovation to both drive and steer the bioeconomy transition. This includes monitoring socio-economic indicators across all sectors and sub-sectors regarding competitiveness, market development, jobs, and turnover.

In summary, there is a need to monitor, among other issues (1) the overall development of the bioeconomy, ensuring a transition to a sustainable economic system on a viable biophysical basis, (2) the processes and shifts within the bioeconomy transition itself to support and steer innovation toward smart solutions, such as cascading use of biomass, and (3) the effects of innovations which follow bionic principles while reducing the pressure on natural ecosystems, such as industrial photosynthesis.

3. Toolbox for a systemic monitoring

A systemic monitoring must cover multiple scales of analysis, be able to link changes in the economy to impacts on the environment, and provide sufficient detail to answer policy relevant questions regarding specific aspects of the bioeconomy in an overarching framework. This has two implications:

1) modeling is a key aspect of a systemic bioeconomy monitoring framework, accompanied by further approaches such as economy-wide resource accounting and life-cycle analysis;
2) sustainability indicators and targets are essential to evaluate whether the bioeconomy transition is contributing to sustainable development.

3.1. *Models and methods to monitor and forecast bioeconomy development*

Fig. 2 illustrates the types of models and approaches that are used to model the bioeconomy with respect to land use and land use change. It is intended to provide a schematic overview of how different model types fit into the bioeconomy monitoring system and to illustrate the wide range of models and methods needed to join multiple scales and dimensions of the bioeconomy into one systemic framework. However, it should be noted that grouping models is a challenge as there are a number of overlaps among model types and categories and several models address multiple scales of analysis. The models in Fig. 2 are roughly portrayed as environmental or economic models, relating loosely to the drivers and state stages of the DPSIR Framework, represented by the dark-shaded economy and environment boxes in Fig. 1, whereas pressures, impacts and responses are modeled. This

[1] Drivers, Pressures, State, Impacts, Responses: this is a causal framework for describing the interactions between society and the environment from a systems analysis perspective. In other words, social and economic developments within the economy (*drivers*) exert *pressure* on the environment and, as a result, the *state* of the environment changes with *impacts* on environment and society. Policy r*esponses* intervene to drive the system toward more sustainability.