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Research paper

A systematic review of the conceptual differences of environmental assessment and ecosystem service studies of biofuel and bioenergy production

Markus A. Meyer*, Florian S. Leckert

Department of Geography, University of Munich (LMU), Munich, Germany

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ABSTRACT

National or supranational policies such as the EU Renewable Energy Directive (EU RED) prescribe both the assessment of the environmental impacts of biofuel and bioenergy production, as well as their impact on ecosystem services (ESS). However, it is not clear what differentiates environmental assessment (EA) and ESS studies. Therefore, we conducted a systematic review and compared ESS and EA studies of biofuel and bioenergy production. We focused on topics such as whether both approaches allow for a holistic sustainability assessment of biofuel/bioenergy production, are suitable for practitioners, and which gaps for policymaking they can bridge. The results of the systematic review suggest that ESS studies tend to assess economic and social sustainability more prominently when compared to EA studies. Furthermore, ESS studies often assess ESS bundles and thereby cover multiple environmental impact categories, while EA studies focus more on selected environmental impacts (e.g., GHG emissions, air pollution, water quality and availability), targeting fewer environmental impacts to achieve slightly more feasible and reliable impact assessments (lower uncertainty). EA studies are dominated by life-cycle assessments. Contrastingly, ESS studies rather cover the entire social-ecological dimensions of biofuel and bioenergy production. Due to their systematic approach, they act as an envelope for multiple methodologies that can quantify the sustainability impacts of biofuel and bioenergy production. In this respect, it can be argued that ESS studies could support policymaking bridging some existing gaps such as the underrepresentation of social assessments in the EU RED.

1. Introduction

To ensure the environmental sustainability of biomass production for biofuels and bioenergy, the EU Renewable Energy Directive (EU RED) prescribes the assessment of their impact on the environment and ecosystem services (ESS) [1]. In this respect, the question arises which aspects differentiate environmental assessments (EA) and ESS studies. It has been argued that, as the number of ESS studies continuously rises, ESS studies could add value to ongoing efforts to assess bioenergy and biofuel sustainability, when compared with existing EAs [2]. For example, governments increasingly implement the ESS concept as it is already evident in more than 60 countries [3]. However, it is not always clear if ESS studies conceptualize human benefits from the environment in a suitable manner or they rather reproduce EAs (e.g., insufficiently consider the social side of the assessment of socio-ecological bioenergy production systems) [2]. This can raise questions whether the ESS approach supports better communication with practitioners and planners through highlighting human-environment interactions, e.g., [4]. Therefore, it is important to understand whether ESS or EA studies have more potential to support practitioners and other decision-makers in biofuel and bioenergy contexts.

ESS are essentially the benefits humans derive from ecosystems [5]. This definition from the Millennium Ecosystem Assessment (MEA) has been refined and advanced by multiple classifications and conceptual frameworks. For example, the Common International Classification of ESSs (CICES) [6] provides a more detailed, nested hierarchical list of ESSs for quantification [7]. In addition,

Abbreviations: CICES, Common International Classification of Ecosystem Services; ESS, ecosystem services; EA, environmental assessment; EIs, environmental impacts; EU RED, EU Renewable Energy Directive; iLUC, indirect land-use change; LCA, life-cycle assessment.

* Corresponding author.
E-mail address: markus.a.meyer@gmail.com (M.A. Meyer).

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there are several attempts to use the ESS approach to assess bioenergy impacts. For example, Gasparatos et al. [8] link biofuels to the ESS approach using the conceptual framework of the Millennium Ecosystem Assessment. Their review identifies the need to go beyond the large number of biofuel EAs and argue to use the ESS approach for investigating the impacts of biofuels/bioenergy (and related policies) on ecosystems and human wellbeing [8,9].

However, the ESS approach is often promoted as an assessment framework that may be applied to multiple scales, to cover all dimensions of sustainability, and to communicate effectively the impact of human land-use decisions on the environment (and its consequent feedback on human wellbeing) [10,11]. On the upside, the economic valuation of ESS using a variety of tools from environmental and ecological economics can increase the policy relevance of the ESS approach [2]. Currently there are several frameworks that try to establish stronger linkages between ESS and their economic value such as the "Mapping and Assessment of Ecosystems and their Services" (MAES) framework (rooted in the ESS cascade) or the TEEB framework [12]. On the downside, the perceived commodification of environmental goods through economic valuation could be an equally strong disadvantage of the ESS approach when compared to EAs [11]. While economic valuation may aggregate the impacts of biofuels and bioenergy on multiple ESS to a single dimension (i.e., one economic value for multiple ESS), it may hide or oversimplify trade-offs or synergies between ESS, thereby narrowing the information available to decision makers (e.g., for prioritizing one over another bundle of ESS). Economic valuation as an additional step in an assessment process can also add uncertainty to the final outcome of the assessment [13].

In the context of biofuels and bioenergy, EAs tend to adopt an overarching assessment approach often focusing on higher-scale impacts such as greenhouse gas (GHG) emissions and air pollution, using established assessment tools such as life-cycle assessments (LCAs) [10]. Multiple LCAs have shown that biofuels emit less GHGs than fossil fuels [14,15]. However, land-use change is a major source of GHG emissions often disregarded in LCAs [8]. Moreover, common EA tools such as LCAs rarely focus on local/regional environmental impacts. In fact the most common local/regional environmental impact categories considered in EAs include soil quality, water quality/availability, biodiversity, and land-use change [10,16].

Currently, there is an interest in comparing how ESS studies can go beyond environmental impact assessments (EIAs). There have been, for example, some attempts to integrate ESS studies in EIAs (or even to replace them) [2], mainly on the basis that the ESS approach has clear links to human wellbeing. However, these attempts are not necessarily relevant for the assessment of the environmental impacts of biofuels and bioenergy, as ESS studies hardly fall into the conceptual focus of EIAs mandated by current legislation in different countries such as the UK [17]. The focus of EIAs is on projects and EIAs usually adopt clear protocols that disregard any impacts beyond those required or prescribed by the regulatory framework they support [2]. EIAs are also more suitable for specific types of projects (e.g., infrastructure) rather than biofuel/bioenergy feedstock production that is likely to affect entire landscapes with high heterogeneity (e.g., short rotation coppice grown in Germany [18]), or produce significant off-site impacts (e.g., sugarcane production in Brazil [19]). Such impacts that are partly unexpected or spatially spread might be better captured through more flexible and comprehensive approaches than EIAs. Furthermore, countries may not require EIAs to evaluate changes in agricultural production due to energy crops such as it is the case in the UK [17]. In the EU RED, certification schemes are compliance instruments for sustainable bioenergy production within the EU (and for imports from other areas), but have very heterogeneous sustainability requirements [10]. This regulatory flexibility may be one reason why EA studies for biofuels and bioenergy are more diverse than EIAs. EAs are a mixture of multiple approaches including LCAs, biodiversity assessments, or water use and quality indicators as collected by the Global Bioenergy Partnership [20].

The aim of this study is to analyze the conceptual differences between EA and ESS studies in the context of biofuels and bioenergy. In order to achieve this, we undertake a systematic review of the current literature on EAs and ESS related to bioenergy and biofuel production. We hypothesize that:

1. multiple conceptual differences exist between EA and ESS studies in the domain of biofuel and bioenergy production;
2. clustering approaches can identify clusters of EA and ESS with distinct characteristics;
3. there will be no consistent differences between ESS and EA studies for certain criteria.

Section 2 describes the main evaluation criteria and the methodology used in our systematic literature review. Section 3 identifies the main clusters of EA and ESS studies, and highlights some of their similarities and differences. Section 4 puts the results of the systematic review into the scientific context and identifies how different types of studies can inform decision-makers and practitioners in biofuel and bioenergy contexts.

2. Material and methods

2.1. Study selection approach

To test our hypotheses, we conduct a systematic literature review based on a Web of Science keyword search (November 22, 2015) for journal articles with a range of search parameters as indicated in detail in the Supplementary Electronic Material. Both for ESS and EA, we selected studies with a focus on the environment (Table 1).

Beyond the selected studies, our keyword search identified studies that were eventually excluded. When it comes to ESS studies, the excluded studies did not provide an assessment per se (e.g., reviews, opinion papers), only assessed biodiversity, did not assess explicitly ESS and/or did not evaluate biofuels/bioenergy (Table 1). For EAs, we excluded studies that focused exclusively on economic or social assessments of biofuels and/or bioenergy.

For the purpose of this study, we perform a systematic review instead of a meta-analysis. This is because a meta-analysis cannot provide a proper comparison of multiple characteristics in different dimensions, especially when qualitative information is reported among the studies. A meta-analysis would have required studies with a similar quantitative indicator under different biofuel/bioenergy production conditions (e.g., mean species richness for biodiversity [21]), which is not very common in the biofuel/bioenergy literature. On the contrary, a systematic review approach can allow the comparison among studies that capture different environmental impacts or ESS, and use various assessment indicators. Finally, it should be mentioned that in contrast to narrative reviews, a systematic review with semi-quantitative evaluation criteria facilitates the aggregation of the literature to groups of comparable studies, allowing for a richer understanding of trends in the existing literature.

After selecting the studies to be reviewed, we cross-map them according to a series of categories and criteria (Section 2.2). These include the overarching themes of the assessment (Section 2.2.1), the environmental impact categories considered (Section 2.2.2), the quality of the approach (Section 2.2.3), and the dimensions of

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